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STABILITY OF STONE- AND DOLOS-ARMORED BUBBLE-MOUND

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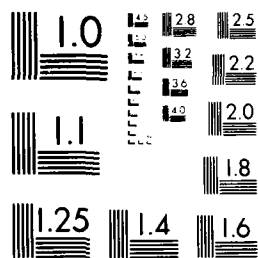
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TECHNICAL REPORT CERC-87-18

STABILITY OF STONE- AND DOLOS-ARMORED RUBBLE-MOUND BREAKWATER HEADS SUBJECTED TO NONBREAKING WAVES WITH NO OVERTOPPING

by

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Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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19 ABSTRACT (Continue on reverse if necessary and identify by block number) The purpose of the investigation herein was to obtain design information for stone and dolos armor used on breakwater heads and subjected to nonbreaking waves. More specifically, it was desired to determine the minimum weight of individual armor units (with given specific weights) required for stability as a function of a. Type of armor unit. b. Sea-side slope of the structure. c. Angle of wave attack. d. Wave period. e. Wave height. (Continued)					
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19. ABSTRACT (Continued).

Based on tests and results described herein, in which stone and dolos armor are used on conical breakwater heads and subjected to nonbreaking waves with angles of wave attack of 0, 45, 90, and 135 deg, it is concluded that:

- a. The longer wave periods (2.00 and 2.75 sec) generally produce the lower stabilities;
- b. Angles of wave attack of 45 and 90 deg are the most critical;
- c. Flattening the slope from 1V on 1.5H to 1V on 2H does not improve stability of the stone armor.

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PREFACE

Authority for the US Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC), to conduct this study was granted by the Office, Chief of Engineers (OCE), US Army Corps of Engineers, under Work Unit 31269, "Stability of Breakwaters," Coastal Structure Evaluation and Design Program, Coastal Engineering Area of Civil Works Research and Development. OCE Technical Monitors for this research were Messrs. John H. Lockhart, Jr., and John G. Housley. CERC Program Manager is Dr. C. Linwood Vincent.

The study was conducted by personnel of CERC under general direction of Dr. James R. Houston, Chief, CERC, and Mr. Charles C. Calhoun, Jr., Assistant Chief, CERC. Direct supervision was provided by Messrs. C. Eugene Chatham, Chief, Wave Dynamics Division (CW), and D. Donald Davidson, Wave Research Branch (CW-R). This report was prepared by Mr. Robert D. Carver, Project Engineer, and Ms. Brenda J. Wright and Mr. C. Ray Herrington, Engineering Technicians, CW-R. The model was operated by Ms. Wright and Messrs. Herrington and Marshall P. Thomas, Engineering Technicians, with Mr. Herrington serving as lead technician. This report was typed by Ms. Myra Willis, CW-R, and edited by Ms. Shirley A. J. Hanshaw, Information Products Division, Information Technology Laboratory, WES.

COL Dwayne G. Lee, CE, was Commander and Director of WES during report publication. Dr. Robert W. Whalin was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI
(metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
feet	0.3048	metres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
square feet	0.09290304	square metres

STABILITY OF STONE- AND DOLOS-ARMORED RUBBLE-MOUND BREAKWATER
HEADS SUBJECTED TO NONBREAKING WAVES WITH NO OVERTOPPING

PART I: INTRODUCTION

Background

1. The experimental investigation described herein constitutes a portion of a research effort to provide engineering data for the safe and economical design of rubble-mound breakwaters. In this study, a rubble-mound breakwater is defined as a protective structure constructed with a core of quarry-run stone, sand, or slag and protected from wave action by one or more stone underlayers and a cover layer composed of selected quarrrystone or specially shaped concrete armor units.

2. Previous investigations have yielded a significant quantity of design information for (a) quarrrystone (Hudson 1958 and Carver 1980, 1983); (b) quadripods, tribars, modified cubes, hexapods, and modified tetrahedrons (Jackson 1968); (c) dolosse (Carver and Davidson 1977 and Carver 1983); and (d) toskane (Carver 1978) which allow selection of armor type and weight for use on structure trunks. However, a systematic investigation of the stability response of breakwater heads has not been undertaken.

3. A proposed structure may necessarily be designed for either non-breaking or breaking waves depending upon positioning of the breakwater and severity of anticipated wave action during its economic life. Some local wave conditions may be of such magnitude that the protective cover layer must consist of specially shaped concrete armor units in order to provide economic construction of a stable breakwater; however, many local design requirements are most advantageously met by quarrrystone armor. This particular report addresses the use of stone and dolos armor on breakwater heads subject to non-breaking waves.

Purpose of Study

4. The purpose of the present investigation was to obtain as much design information for stone and dolos armor used on breakwater heads and

subjected to nonbreaking waves as possible. More specifically, it was desired to determine the minimum weight of individual armor units (with given specific weights) required for stability as a function of

- a. Type of armor unit.
- b. Sea-side slope of the structure.
- c. Angle of wave attack.
- d. Wave period.
- e. Wave height.

PART II: TESTS

Stability Scale Effects

5. If the absolute sizes of experimental breakwater materials and wave dimensions become too small, flow around the armor units enters the laminar regime; and the induced drag forces become a direct function of the Reynolds number. Under these circumstances, prototype phenomena are not properly simulated, and stability scale effects are induced. Hudson (1975) presents a detailed discussion of the design requirements necessary to ensure the preclusion of stability scale effects in small-scale breakwater tests and concludes that scale effects will be negligible if the Reynolds stability number

$$R_N = \frac{g^{1/2} H^{1/2} l_a}{\nu}$$

where

g = acceleration due to gravity, ft/sec^2 *

H = wave height, ft

l_a = characteristic length of armor unit, ft

ν = kinematic viscosity of experimental fluid medium, ft^2/sec

is equal to or greater than 3×10^4 . For all tests reported herein, the sizes of experimental armor and wave dimensions were selected such that scale effects were insignificant (i.e., R_N was greater than 3×10^4).

Method of Constructing Test Sections

6. All experimental breakwater sections were constructed to reproduce as closely as possible results of the usual methods of constructing full-scale breakwaters. The core material was dampened as it was dumped by bucket or shovel into the flume and was compacted with hand trowels to simulate natural consolidation resulting from wave action during construction of the prototype

* For convenience, symbols and abbreviations are listed in the Notation (Appendix A).

structure. Once the core material was in place, it was sprayed with a low-velocity water hose to ensure adequate compaction of the material. Then the underlayer stone was added by shovel and smoothed to grade by hand or with trowels. No excessive pressure or compaction was applied during placement of the underlayer stone. Armor units used in the cover layers were placed in a random manner corresponding to work performed by a general coastal contractor, i.e., they were individually placed but were laid down without special orientation or fitting. After each test series the armor units were removed from the breakwater; all of the underlayer stones were replaced to the grade of the original test section; and the armor was replaced.

Test Equipment and Materials

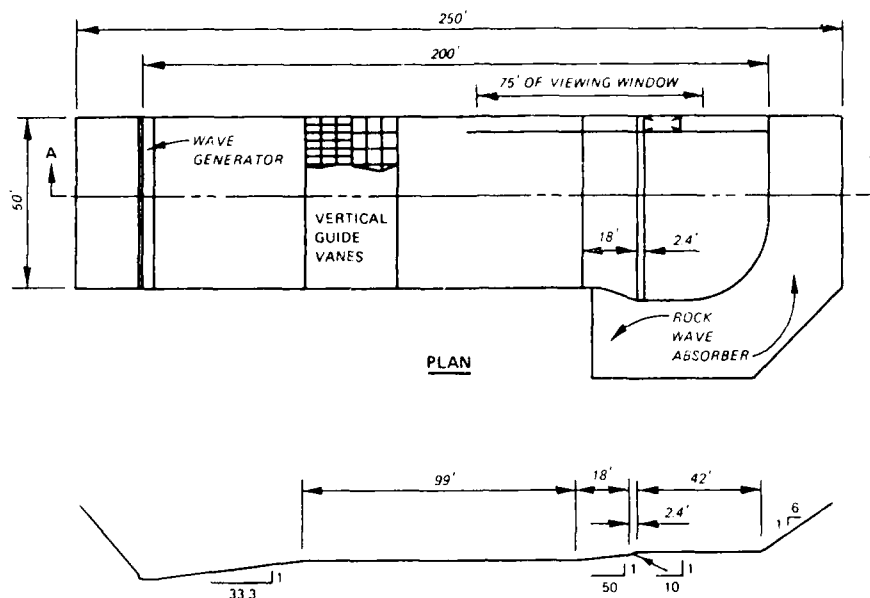
Equipment

7. All stability tests were conducted in an L-shaped concrete flume 250 ft* long, 50 and 80 ft wide at the top and bottom of the L, respectively, and 4.5 ft deep (Figure 1). The flume is equipped with a paddle wave generator capable of producing sinusoidal waves of various periods and heights. For all tests, waves of the required characteristics were generated by varying the frequency and amplitude of the paddle motion. Changes in water surface elevation as a function of time (wave heights) were measured by electrical wave height gages in the vicinity where the toe of the test sections was to be placed and recorded on chart paper by an electrically operated oscillograph. The electrical output of the wave gages was directly proportional to their submergence depth. Test sections were constructed on the flat bottom portion of the flume, about 130 ft from the wave generator.

Material

8. Rough, hand-shaped granitic stone W_a with an average length of approximately two times its width, average weight of 0.55 lb, and a specific weight of 167 pcf was used to armor the stone sections. Dolos sections were armored with 0.276-lb units that have a specific weight of 142.2 pcf. Sieve-sized limestone ($\gamma_a = 165.0$ pcf) was used for the underlayers and core.

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.



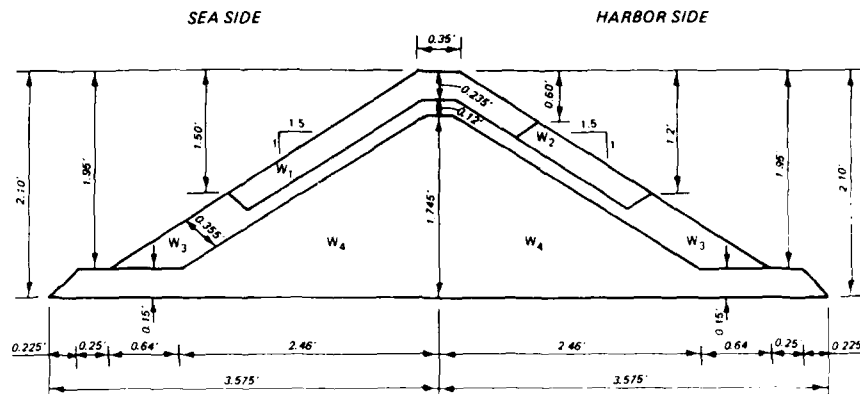
SECTION A-A

Figure 1. Wave basin geometry

Selection of Test Conditions

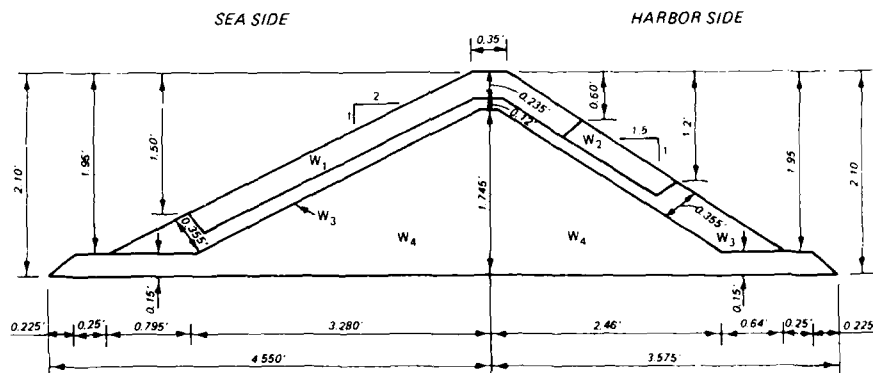
9. Tests were conducted on stone and dolos conical head sections of the type shown in Figures 2-5 and Photos 1-12. Sea-side slopes of 1V on 1.5H and 1V on 2H were investigated, while the beach-side slope was held constant at 1V on 1.5H. Wave periods of 1.25, 1.5, 2.0, and 2.75 sec were simulated, thus assuring a wide range of wave steepness H/L . The water depth was 1.5 ft. Angles of wave attack θ were 0, 45, 90, and 135 deg (Figures 6 and 7).

10. Design wave heights for the no-damage criterion were determined by subjecting the test sections to monochromatic waves successively larger in height in 0.01- to 0.02-ft increments until the maximum heights for which the armor was stable were reached. Each test wave was allowed to attack the breakwater for a cumulative period of 30 min, then the test sections were rebuilt prior to attack by the next added increment wave. This 30-min



LEGEND	
SYMBOL	MATERIAL CHARACTERISTICS
W_1	0.276-LB DOLOS OR 0.55-LB STONE
W_2	0.28-LB STONE
W_3	0.055-LB STONE
W_4	0.000138- TO 0.0028-LB STONE

Figure 2. Typical breakwater cross section, 1V-on-1.5H structure slope



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Figure 3. Typical breakwater cross section, 1V-on-2H structure slope

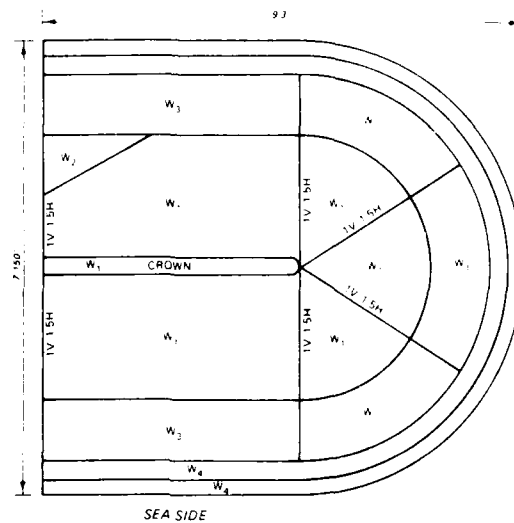


Figure 4. Typical plan view, LV-on-1.5H structure slope

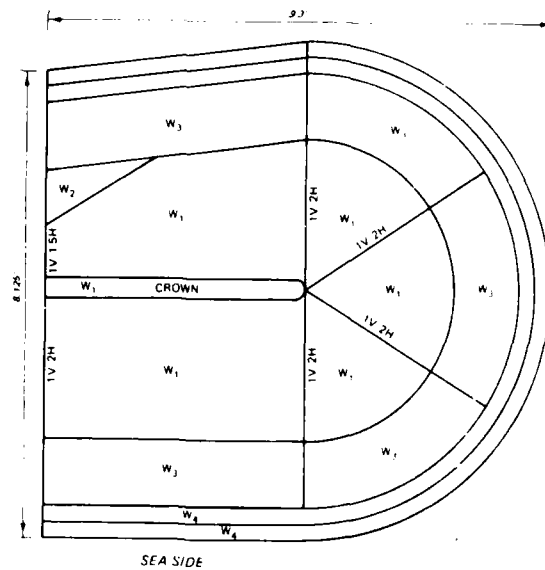


Figure 5. Typical plan view, LV-on-2H structure slope

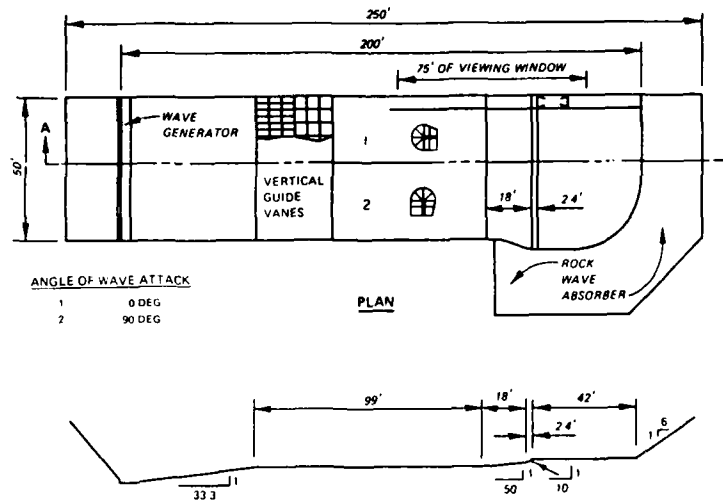


Figure 6. Test section orientations for 0- and 90-deg wave attack

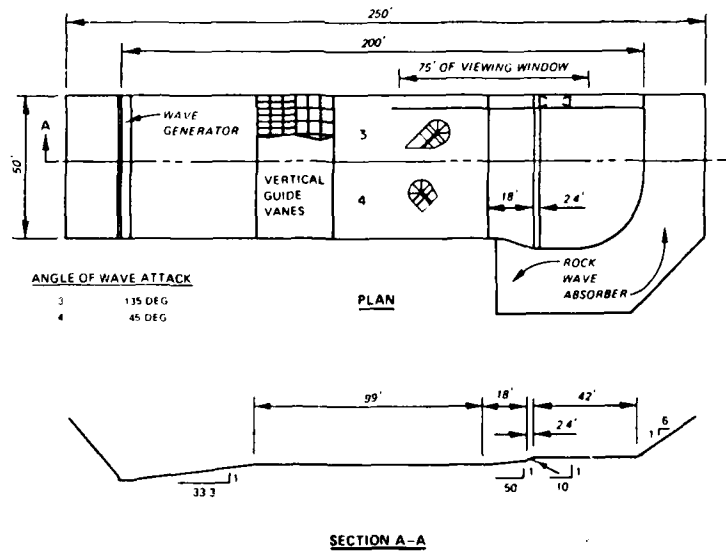


Figure 7. Test section orientations for 45- and 135-deg wave attack

interval allowed sufficient time for the test sections to stabilize, i.e., time for all significant movement of armor material to abate. During tests, the wave generator was stopped as soon as reflected waves from the breakwater reached it, and the waves were allowed to decay to zero height before restarting the generator in order to prevent the test sections from being exposed to uncontrolled wave groups and/or an undefined wave spectrum.

PART III: TEST RESULTS

11. Stability test results for stone and dolos armor are summarized in Tables 1 and 2, respectively. Presented therein are experimentally determined design wave heights and corresponding stability numbers as functions of wave period, wave steepness, and breakwater slope. Breakwater slopes of 1V on 1.5H and 1V on 2H were used for both armor types. The number of armor units per given surface area A was $N = 1.26 \Psi^{-2/3}$, with $n = 2$, $k_{\Delta} = 1.00$, and $P = 37$ percent for stone armor, and $N = 0.83 \Psi^{-2/3}$ with $n = 2$, $k_{\Delta} = 0.94$, and $P = 56$ percent of dolos armor. The variable Ψ is defined as the volume of an individual armor unit. Photos 13-54 show the after-testing stability conditions of the structures.

12. Tests were initially conducted on a 1V-on-2H breakwater slope with 1.25-, 1.50-, 2.00-, and 2.75-sec waves for 0-, 45-, 90-, and 135-deg angles of wave attack. Results of these tests showed the 45- and 90-deg wave directions and the longer wave periods to be the most critical to stability. Therefore, tests on the 1V-on-1.5H slope were conducted with 1.50-, 2.00-, and 2.75-sec waves at 45- and 90-deg angles of wave attack.

13. Figures 8-11 and 12-15 present stability number N_s as a function of wave period and direction for stone and dolos, respectively. Figures 16 and 17 summarize the data by armor type. These data show that the longer wave periods (2.00 and 2.75 sec) generally produce the lower stabilities, and angles of wave attack of 45 and 90 deg are the most critical. Also, it is important to note that flattening the slope to 1V on 2H does not improve stability of the stone armor. Effects of wave direction on dolos stability are consistent with trends previously observed by Willock (1977).

14. Assuming a Hudson stability relationship is applicable to the present data (i.e., the stability coefficient K_D equals $N_s^3 / \cot \alpha$ and using the critical (minimum) values of N_s determined herein), the following is obtained:

Armor Type	$\cot \alpha$	N_s	K_D
Stone	1.5	1.60	2.7
Stone	2.0	1.60	2.0
Dolos	1.5	2.26	7.7
Dolos	2.0	2.63	9.1

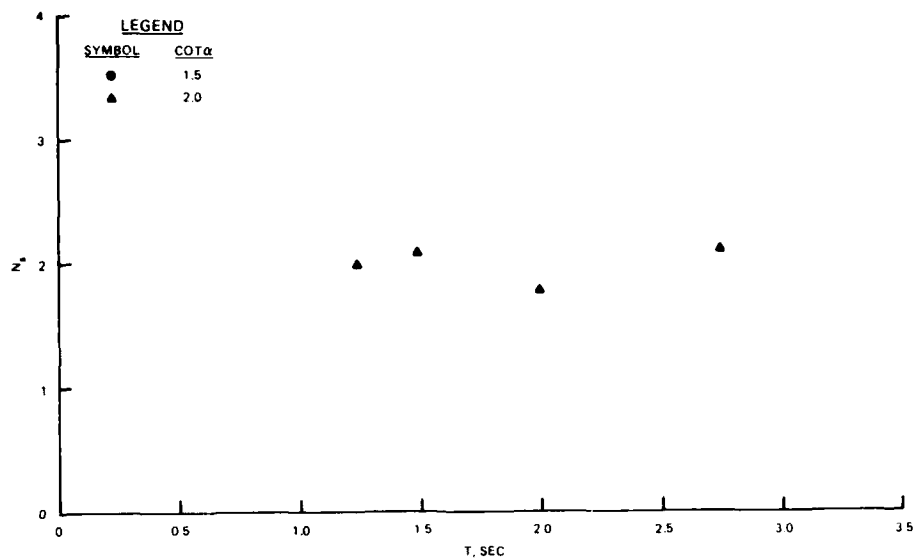


Figure 8. Stone armor stability number N_s versus wave period T ,
0-deg wave attack

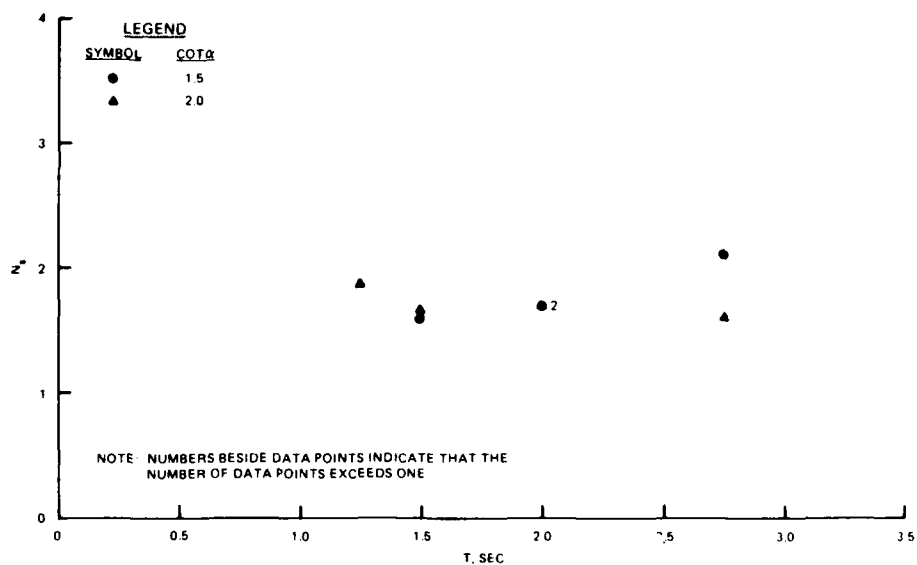


Figure 9. Stone armor stability number N_s versus wave period T ,
45-deg wave attack

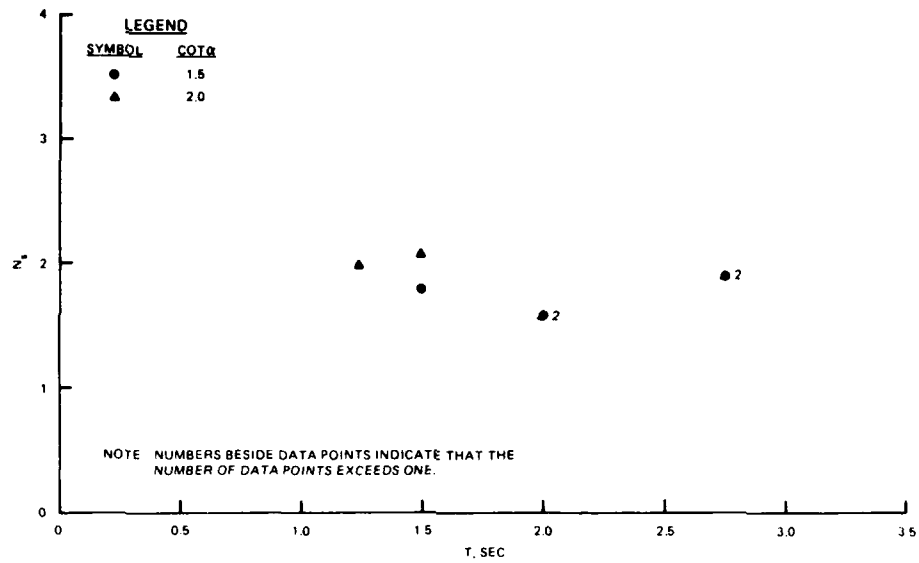


Figure 10. Stone armor stability number N_s versus wave period T , 90-deg wave attack

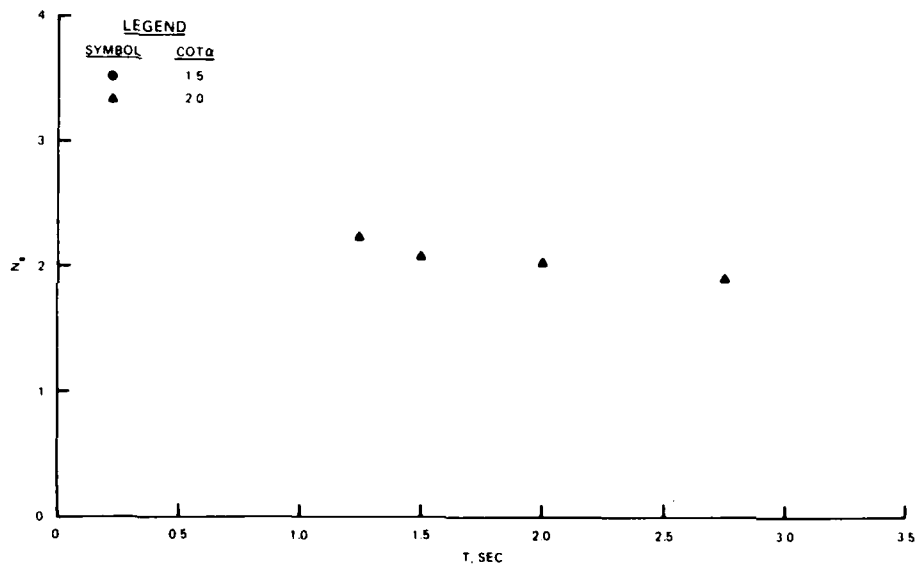


Figure 11. Stone armor stability number N_s versus wave period T , 135-deg wave attack

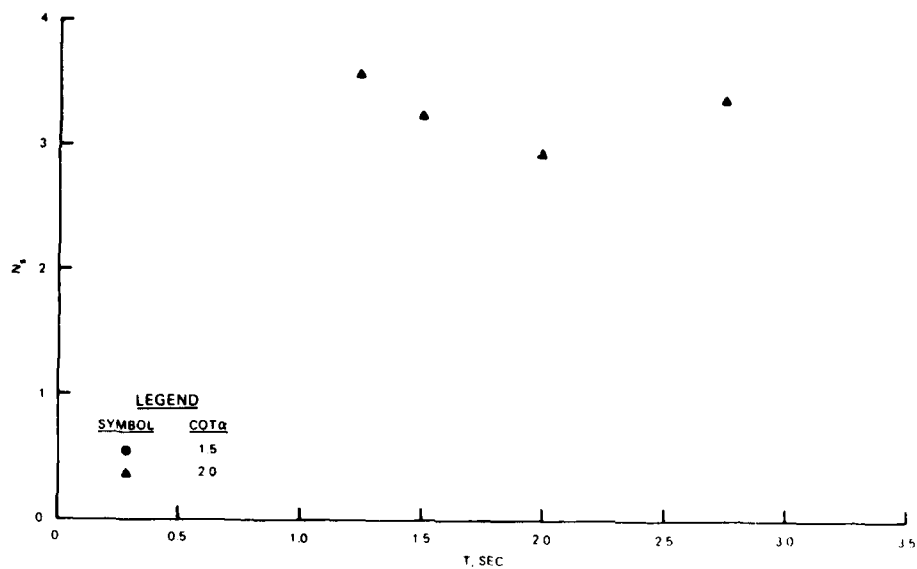


Figure 12. Dolos armor stability number N_s versus wave period T ,
0-deg wave attack

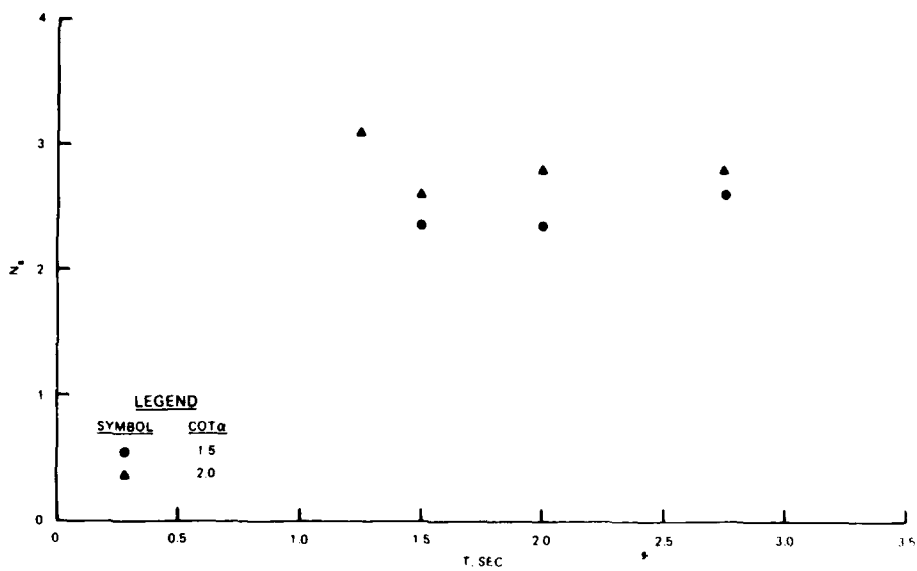


Figure 13. Dolos armor stability number N_s versus wave period T ,
45-deg wave attack

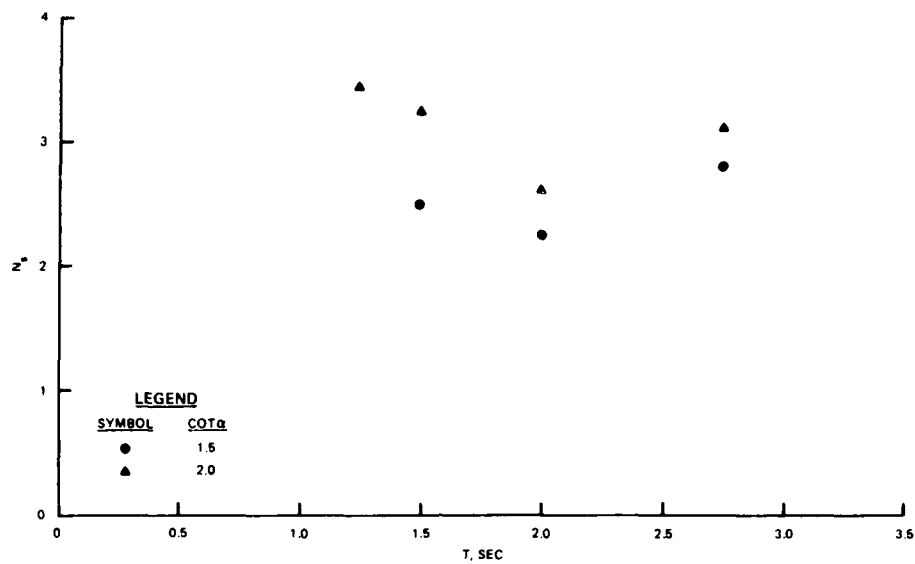


Figure 14. Dolos armor stability number N_s versus wave period T , 90-deg wave attack

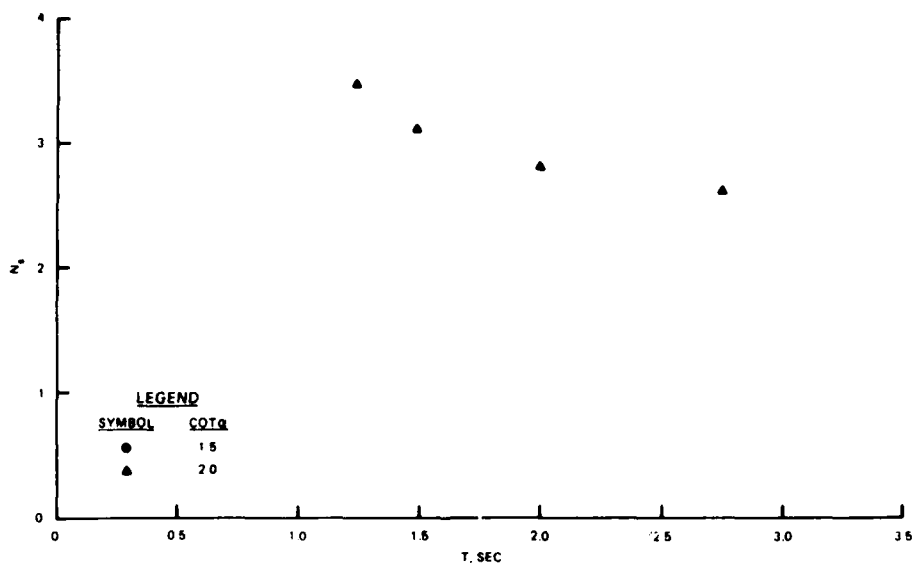


Figure 15. Dolos armor stability number N_s versus wave period T , 135-deg wave attack

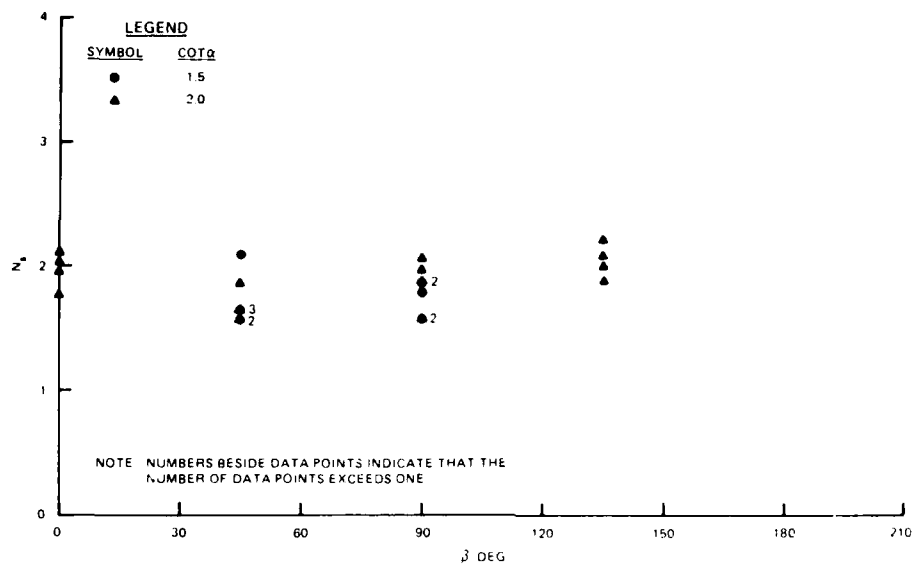


Figure 16. Stone armor stability number N_s versus angle of wave attack β

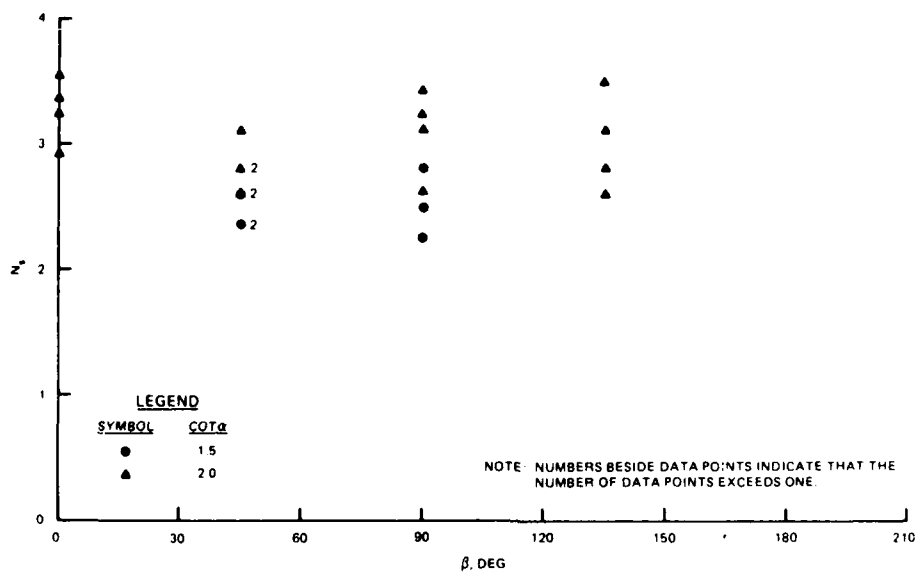


Figure 17. Dolos armor stability number N_s versus angle of wave attack β

These results are extremely significant in that minimum stability coefficients are considerably less than those presented in the Shore Protection Manual (SPM) (1984) and EM 1110-2-2904 (Headquarters, Department of the Army, US Army Corps of Engineers (USACE) 1986).

PART IV: CONCLUSIONS

15. Based on tests and results described herein, in which stone and dolos armor are used on conical breakwater heads and subjected to nonbreaking waves with angles of wave attack of 0, 45, 90, and 135 deg, it is concluded that:

- a. The longer wave periods (2.00 and 2.75 sec) generally produce the lower stabilities.
- b. Angles of wave attack of 45 and 90 deg are the most critical.
- c. Flattening the slope from 1V on 1.5H to 1V on 2H does not improve stability of the stone armor.
- d. Assuming a multiplicity of wave directions, the following values of the stability coefficient K_D are recommended:

<u>Armor Type</u>	<u>Structure Slope</u>	<u>K_D</u>
Stone	1V on 1.5H	2.7
Stone	1V on 2H	2.0
Dolos	1V on 1.5H	7.7
Dolos	1V on 2H	9.1

It should be noted that the K_D values presented in item d are significantly lower than those presently recommended in the SPM (1984) and FM 1110-2-2904 (USACE 1986).

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Table 1
 Values of H , H/L , and N_s for Two Layer. of Stone Armor Randomly
Placed on Breakwater Heads and Subjected to Nonbreaking Waves with No
Overtopping: $W_a = 0.55$ lb; $\gamma_a = 167$ pcf;
 $\cot \alpha = 1.5$ and 2 ; $d = 1.50$ ft

<u>θ, deg</u>	<u>T, sec</u>	<u>H, ft</u>	<u>H/L</u>	<u>N_s</u>
<u>$\cot \alpha = 2.0$</u>				
0	1.25	0.50	0.072	2.00
0	1.50	0.52	0.058	2.09
0	2.00	0.45	0.035	1.80
0	2.75	0.53	0.029	2.13
45	1.25	0.47	0.067	1.88
45	1.50	0.42	0.047	1.68
45	2.00	0.42	0.033	1.68
45	2.75	0.40	0.022	1.60
90	1.25	0.50	0.072	2.00
90	1.50	0.52	0.058	2.09
90	2.00	0.40	0.031	1.60
90	2.75	0.48	0.026	1.92
135	1.25	0.56	0.080	2.25
135	1.50	0.52	0.058	2.09
135	2.00	0.51	0.040	2.04
135	2.75	0.48	0.026	1.92
<u>$\cot \alpha = 1.5$</u>				
45	1.50	0.40	0.044	1.60
45	2.00	0.42	0.033	1.68
45	2.75	0.53	0.029	2.13
90	1.50	0.45	0.050	1.80
90	2.00	0.40	0.031	1.60
90	2.75	0.48	0.026	1.92

Table 2
 Values of H , H/L , and N_s for Two Layers of Dolos Armor Randomly
 Placed on Breakwater Heads and Subjected to Nonbreaking Waves with No
 Overtopping: $W_a = 0.276$ lb; $\cot \alpha = 1.5$ and 2 ; $d = 1.50$ ft

β , deg	T , sec	H , ft	H/L	N_s
<u>Cot $\alpha = 2.0$</u>				
0	1.25	0.57	0.082	3.57
0	1.50	0.52	0.058	3.26
0	2.00	0.47	0.037	2.95
0	2.75	0.54	0.029	3.39
45	1.25	0.50	0.072	3.13
45	1.50	0.42	0.047	2.63
45	2.00	0.45	0.035	2.82
45	2.75	0.45	0.025	2.82
90	1.25	0.55	0.079	3.45
90	1.50	0.52	0.058	3.26
90	2.00	0.42	0.033	2.63
90	2.75	0.50	0.027	3.13
135	1.25	0.56	0.080	3.51
135	1.50	0.50	0.056	3.13
135	2.00	0.45	0.035	2.82
135	2.75	0.42	0.023	2.63
<u>Cot $\alpha = 1.5$</u>				
45	1.50	0.38	0.042	2.38
45	2.00	0.38	0.030	2.38
45	2.75	0.42	0.023	2.63
90	1.50	0.40	0.044	2.51
90	2.00	0.36	0.028	2.26
90	2.75	0.45	0.025	2.82

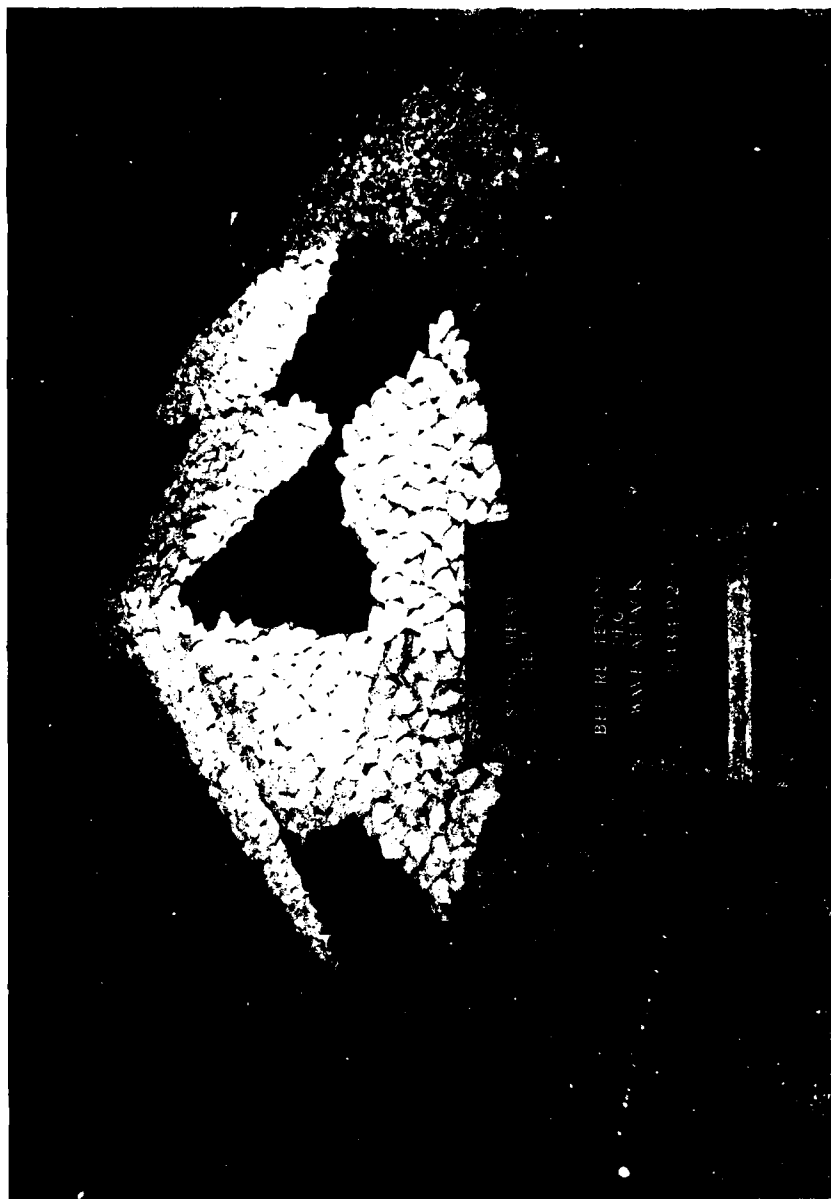


Photo 1. End view of a typical stone section before wave attack at a
IV- on-2H-structure slope; angle of wave attack = 0 deg



Photo 2. Sea-side view of a typical stone section before wave attack at a
1V- on-2H-structure slope; angle of wave attack = 45 deg



Photo 3. End view of a typical stone section before wave attack at a
IV- on-2H-structure slope; angle of wave attack = 90 deg

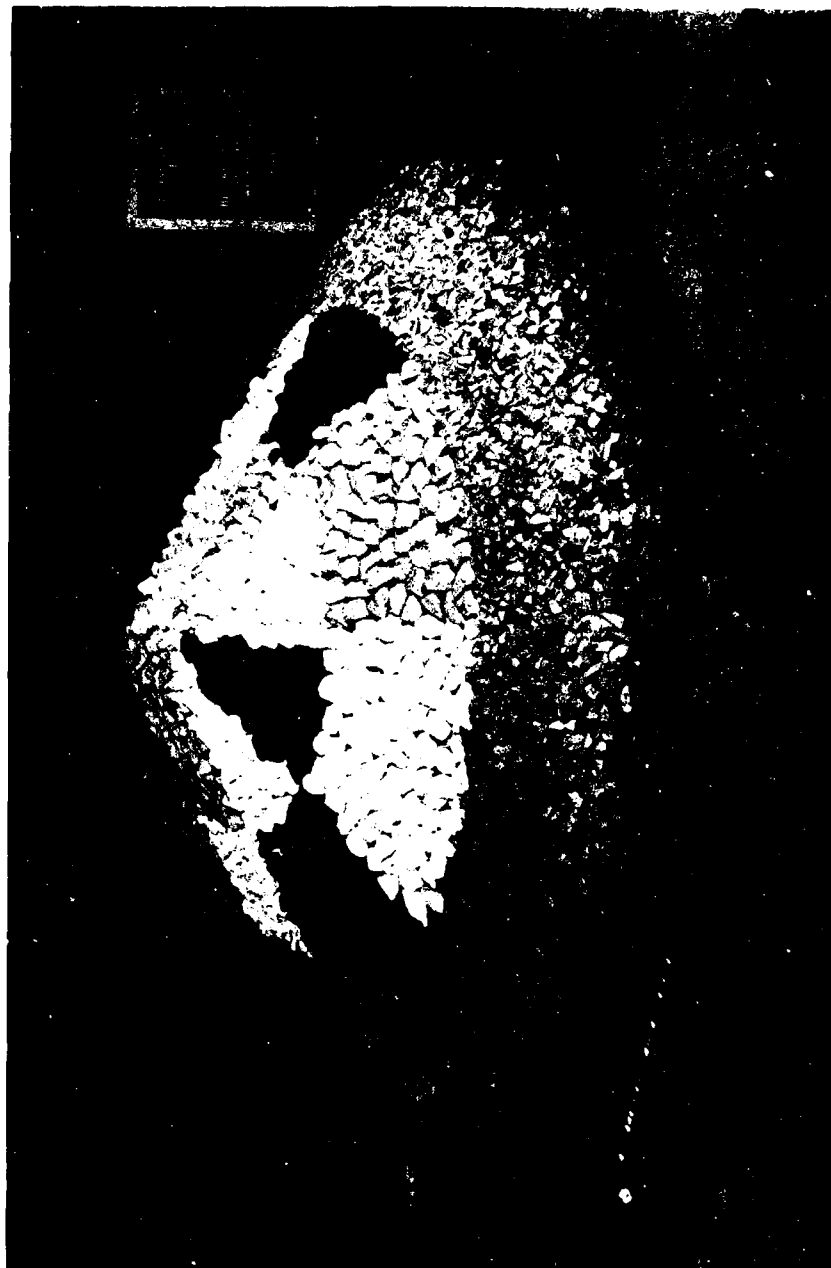


Photo 4. End view of a typical stone section before wave attack at a
IV- on-2H-structure slope; angle of wave attack = 135 deg



Photo 5. End view of a typical stone section before wave attack at a
1V- on-1.5H-structure slope; angle of wave attack = 45 deg

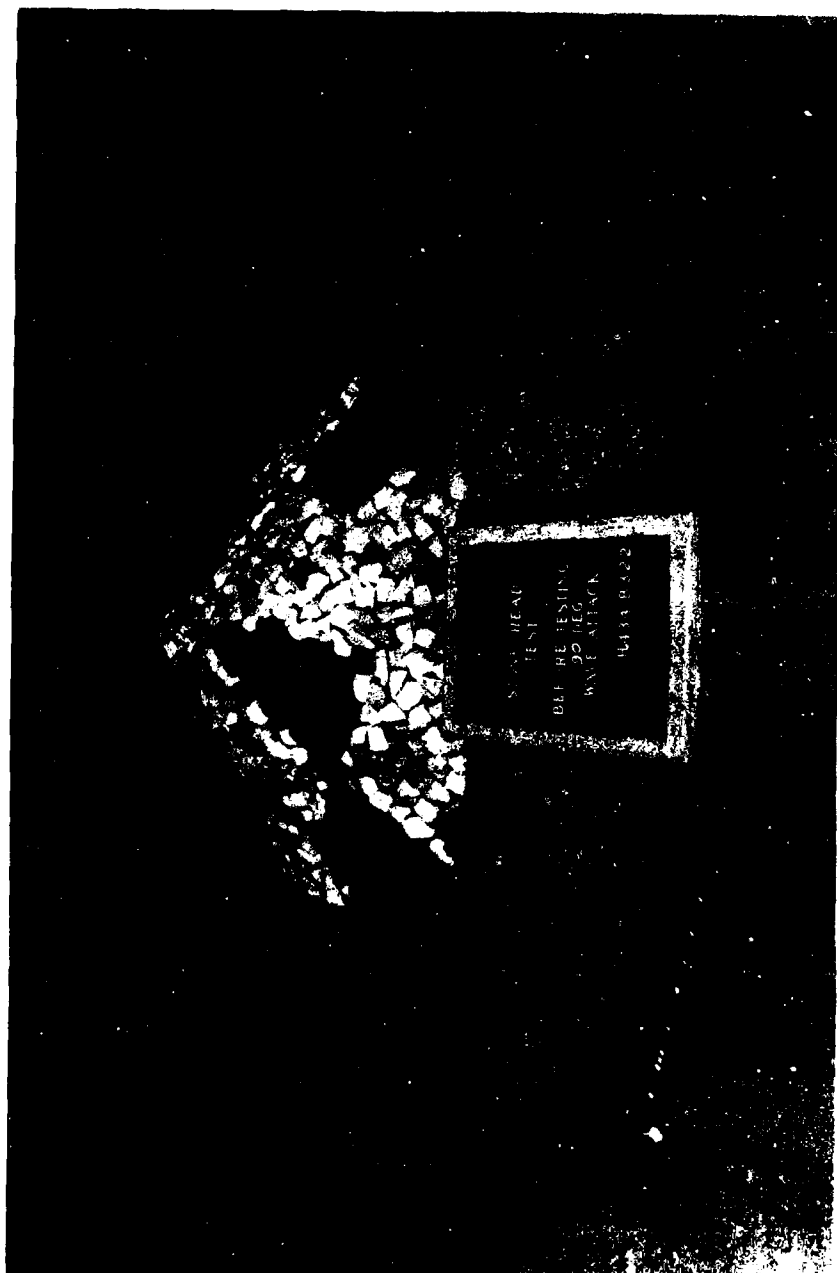


Photo 6. End view of a typical stone section before wave attack at a
1V- on-1.5H-structure slope; angle of wave attack = 90 deg

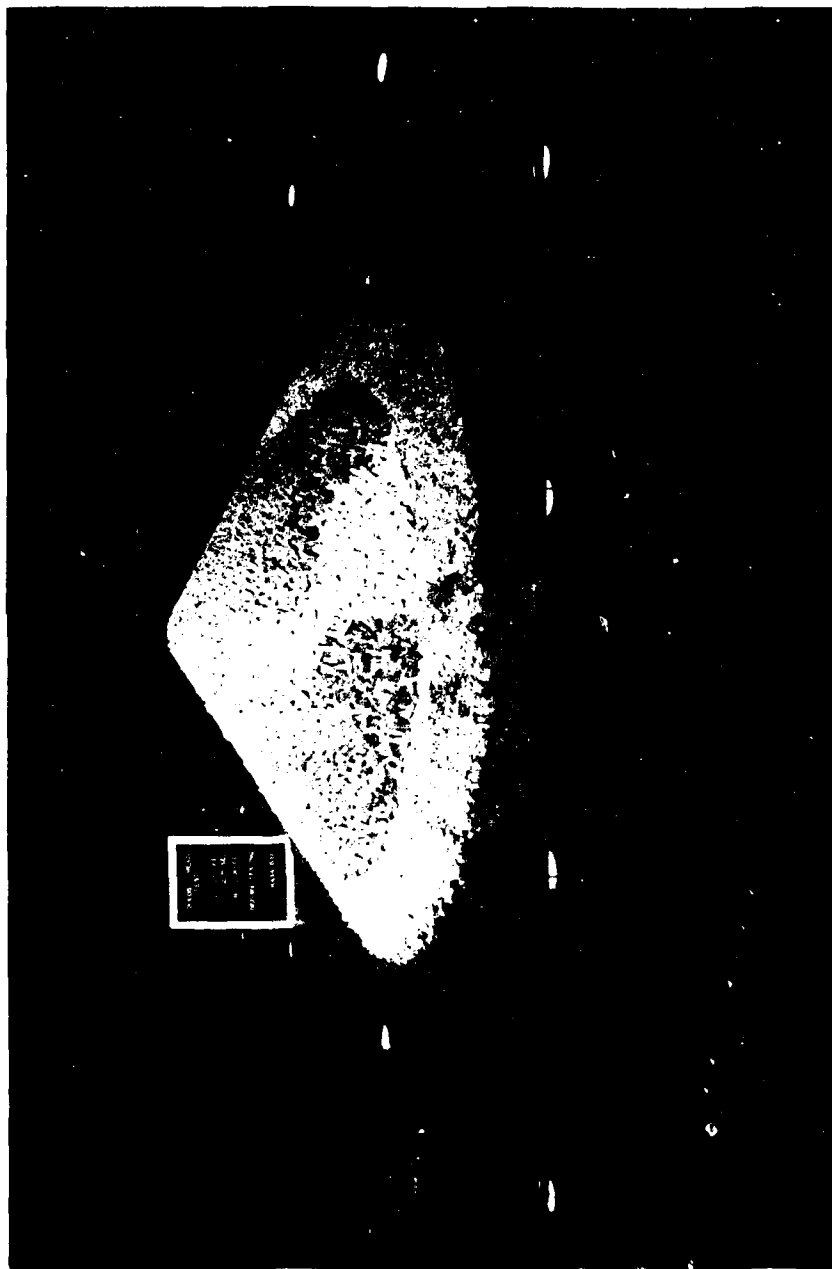


Photo 7. End view of a typical dolos section before wave attack at a
IV- on-2H-structure slope; angle of wave attack = 0 deg



Photo 8. Seaside view of a typical dolos section before wave attack at a
1V- on-2H-structure slope; angle of wave attack = 45 deg



Photo 9. End view of a typical dolos section before wave attack at a
1V- on-2H-structure slope; angle of wave attack = 90 deg

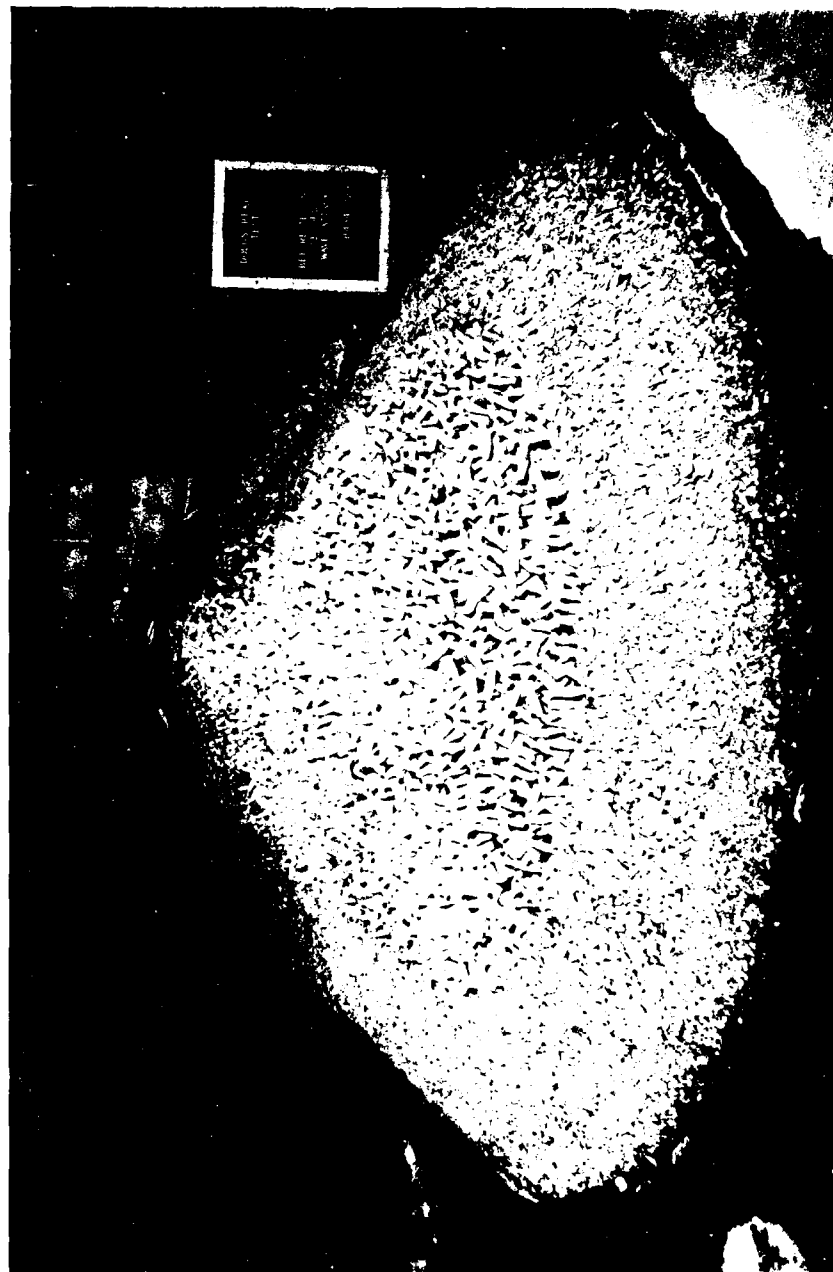
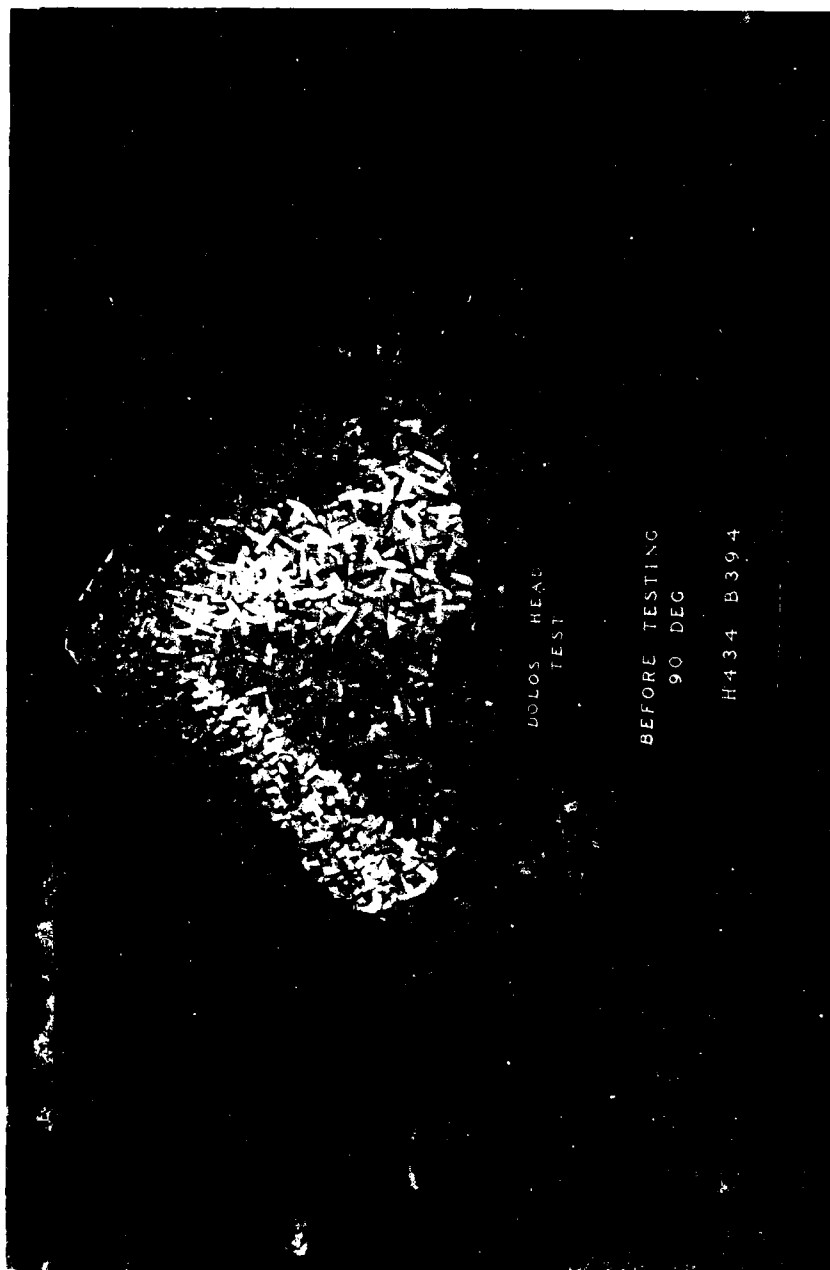


Photo 10. End view of a typical dolos section before wave attack at a
1V- on-2H-structure slope; angle of wave attack = 135 deg



Photo 11. End view of a typical dolos section before wave attack at a
IV- on-1.5H-structure slope; angle of wave attack = 45 deg



DOLOS HEAD
TEST

BEFORE TESTING
90 DEG

H434 B394

Photo 12. End view of a typical dolos section before wave attack at a
IV- on-1.5H-structure slope; angle of wave attack = 90 deg

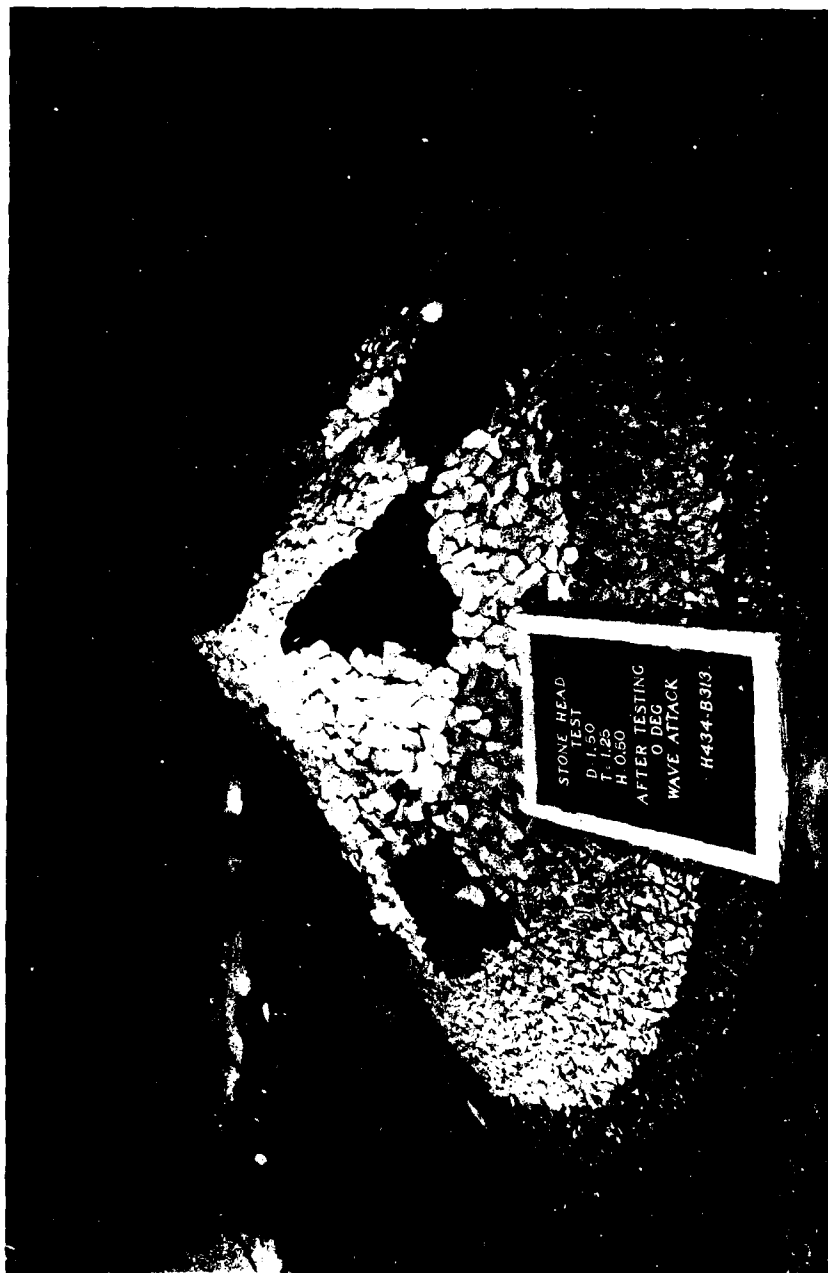


Photo 13. End view after attack of 1.25-sec, 0.50-ft waves; angle of wave attack = 0 deg; 1V- on-2H-structure slope; stone armor

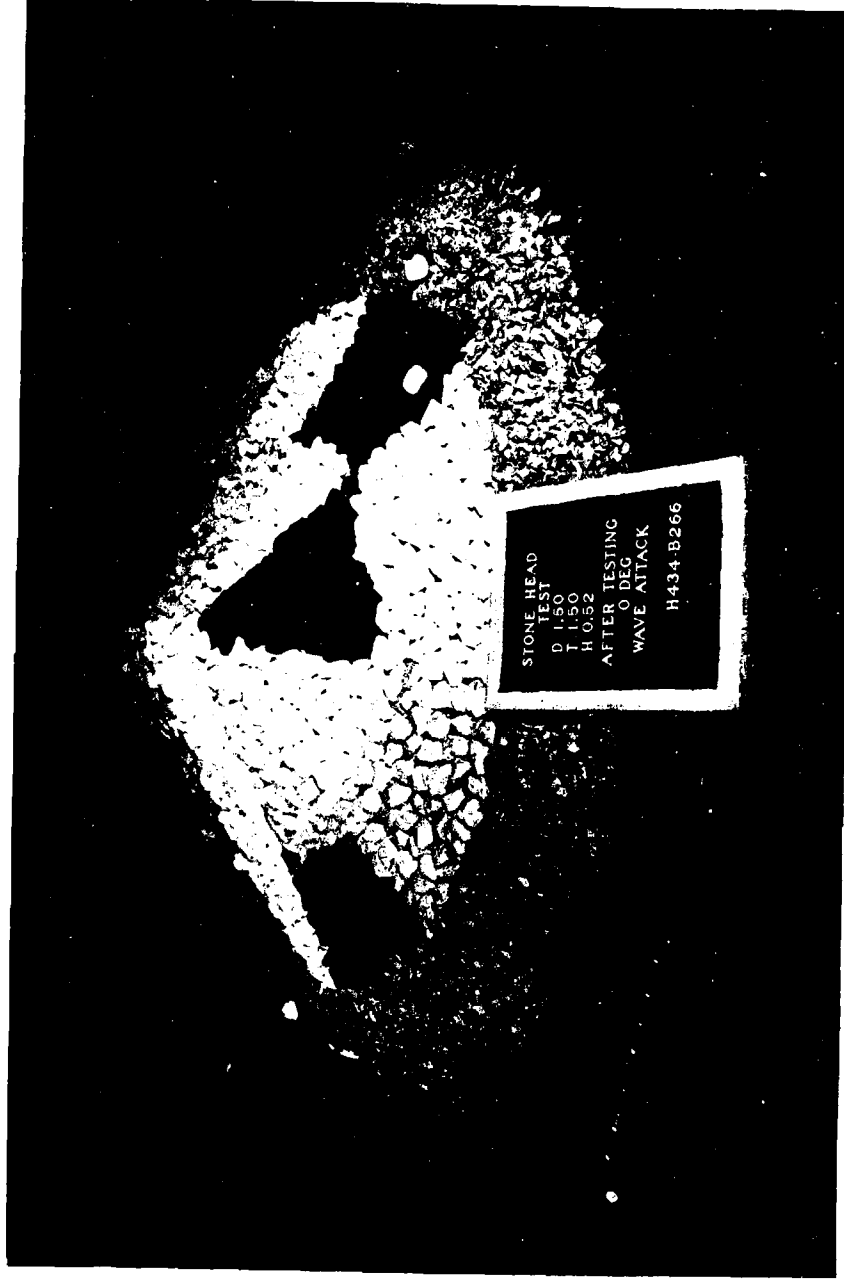


Photo 14. End view after attack of 1.50-sec, 0.52-ft waves; angle of wave attack = 0 deg; 1V- on-2H-structure slope; stone armor

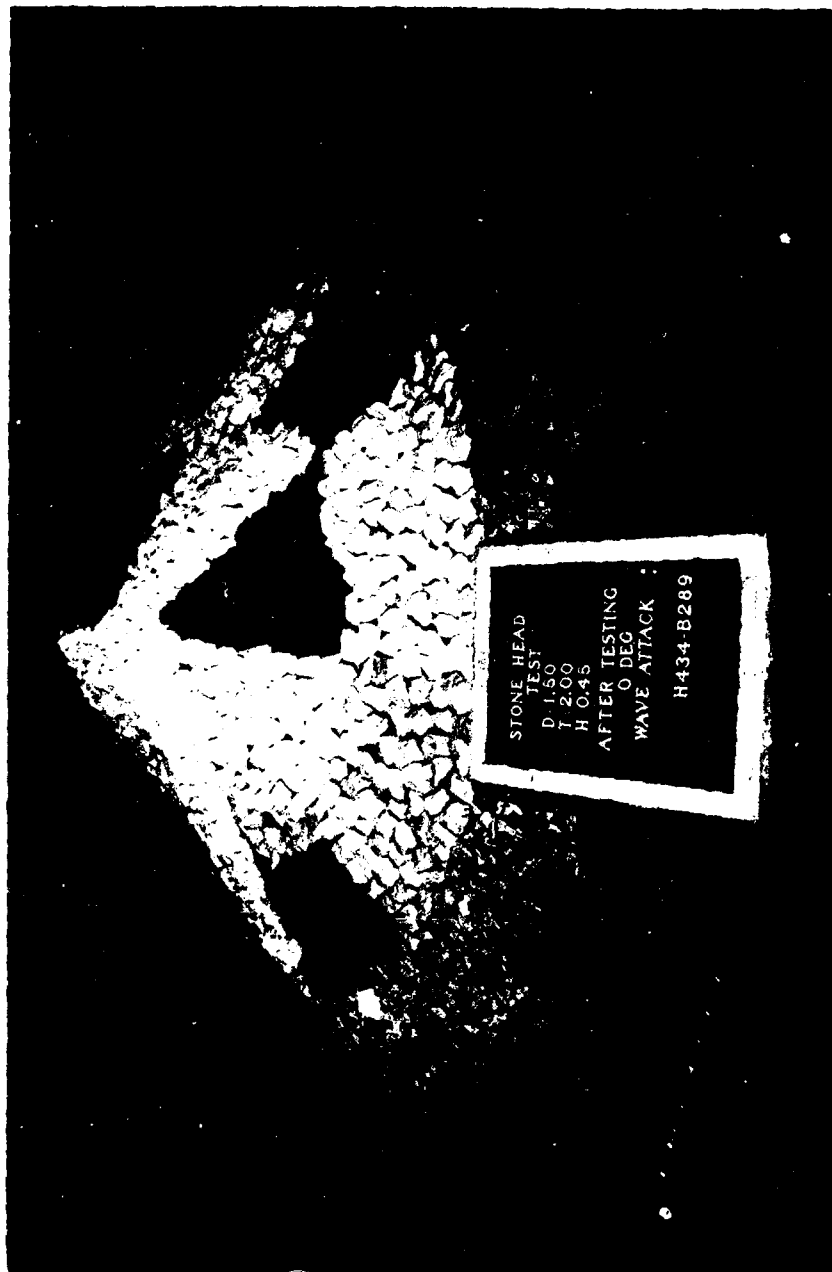


Photo 15. End view after attack of 2.00-sec, 0.45-ft waves; angle of wave attack = 0 deg; 1V- on-2H-structure slope; stone armor

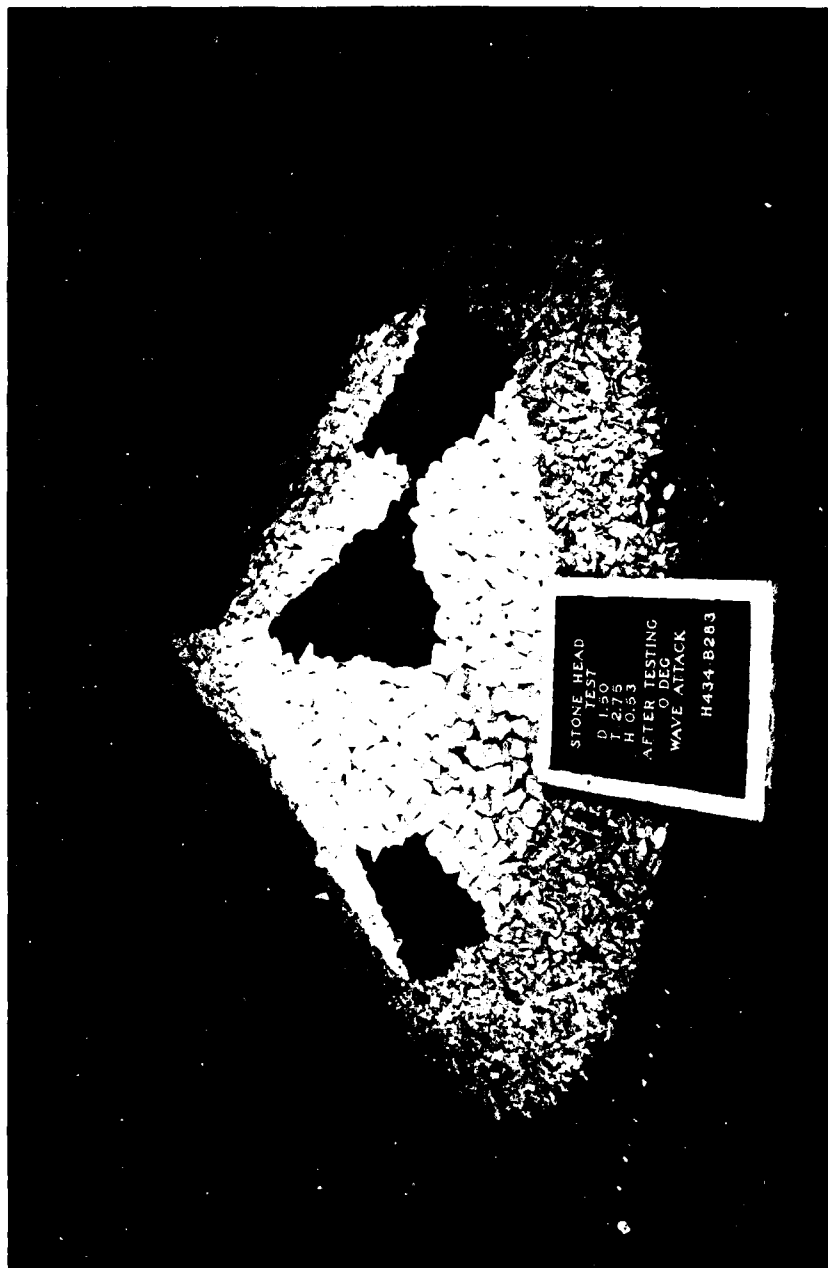


Photo 16. End view after attack of 2.75-sec, 0.53-ft waves; angle of wave attack = 0 deg; IV- on-2H-structure slope; stone armor

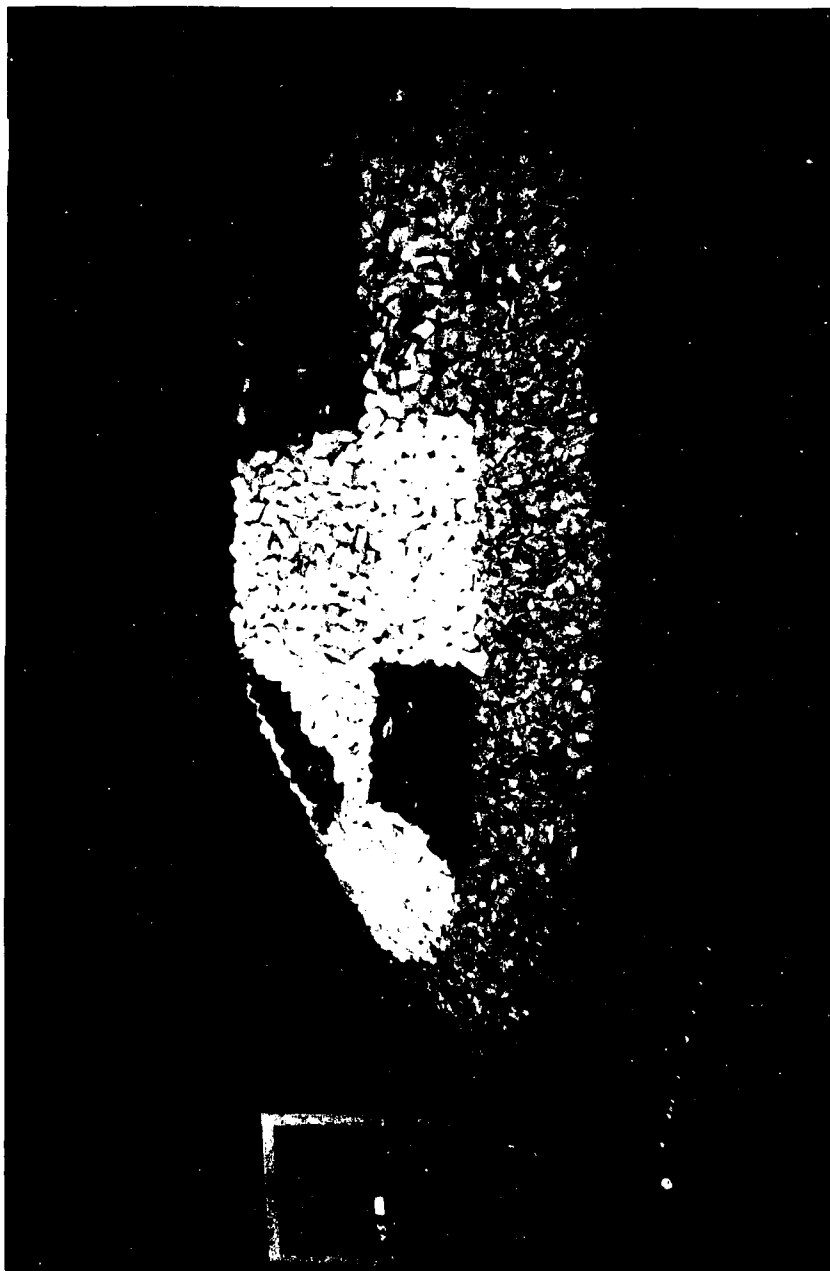


Photo 17. Sea-side view after attack of 1.25-sec, 0.47-ft waves; angle of wave attack = 45 deg; IV- on-2H-structure slope; stone armor



Photo 18. Sea-side view after attack of 1.50-sec, 0.42-ft waves; angle of wave attack = 45 deg; LV- on-2H-structure slope; stone armor



Photo 19. Sea-side view after attack of 2.00-sec, 0.42-ft waves; angle of wave attack = 45 deg; IV- on-2H-structure slope; stone armor



Photo 20. Sea-side view after attack of 2.75-sec, 0.40-ft waves; angle of wave attack = 45 deg; LV- on-2H-structure slope; stone armor



Photo 21. End view after attack of 1.25-sec, 0.50-ft waves; angle of wave attack = 90 deg; 1V - on-2H-structure slope; stone armor

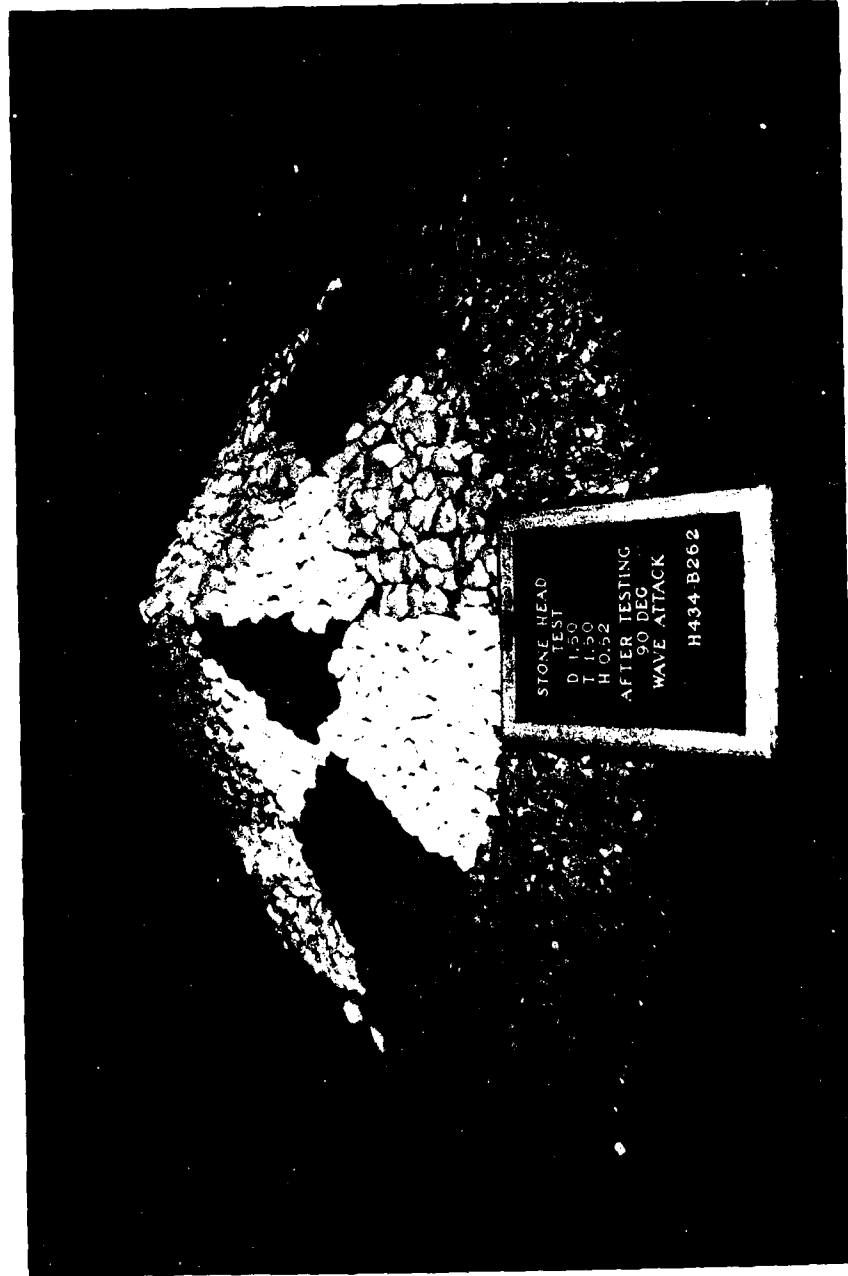


Photo 22. End view after attack of 1.50-sec, 0.52-ft waves; angle of wave attack = 90 deg; LV- on-2H-structure slope; stone armor

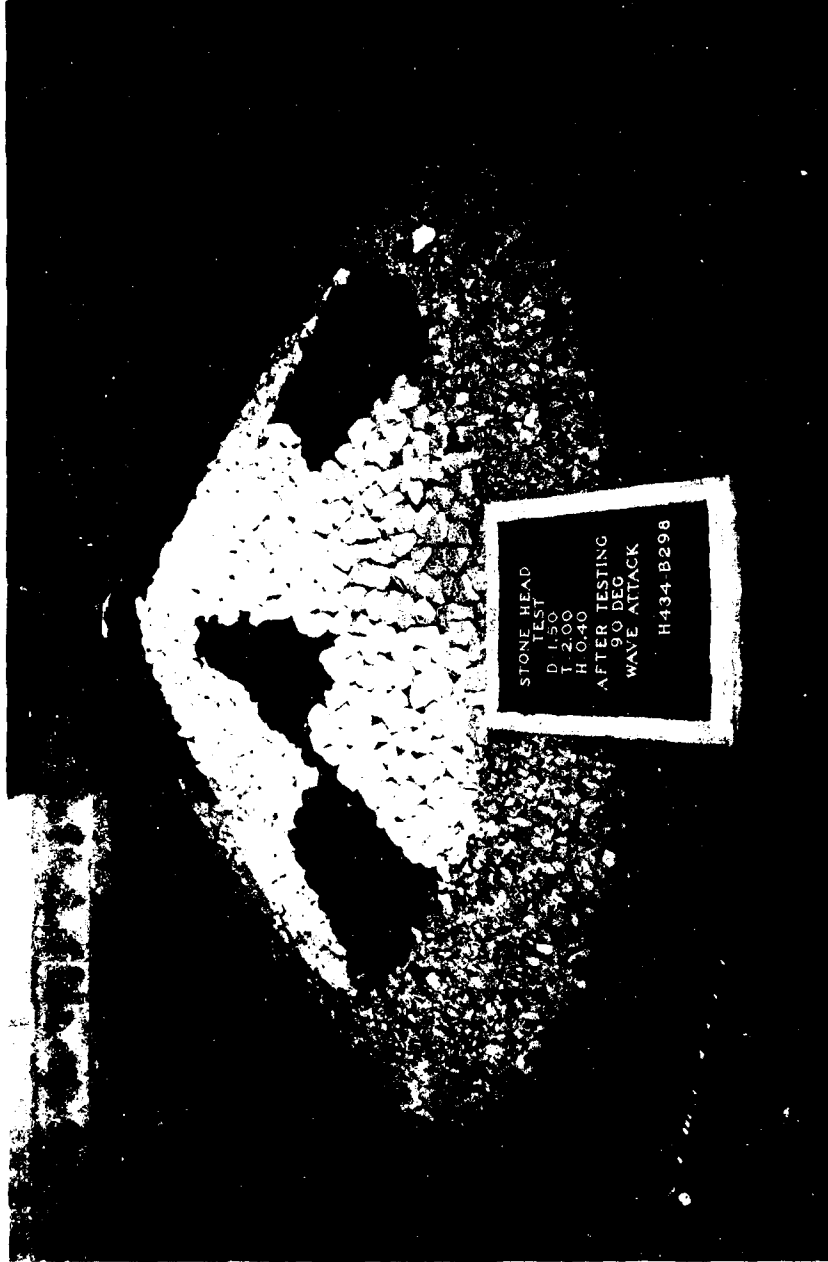


Photo 23. End view after attack of 2.00-sec, 0.40-ft waves; angle of wave attack = 90 deg; IV- on-2H-structure slope; stone armor

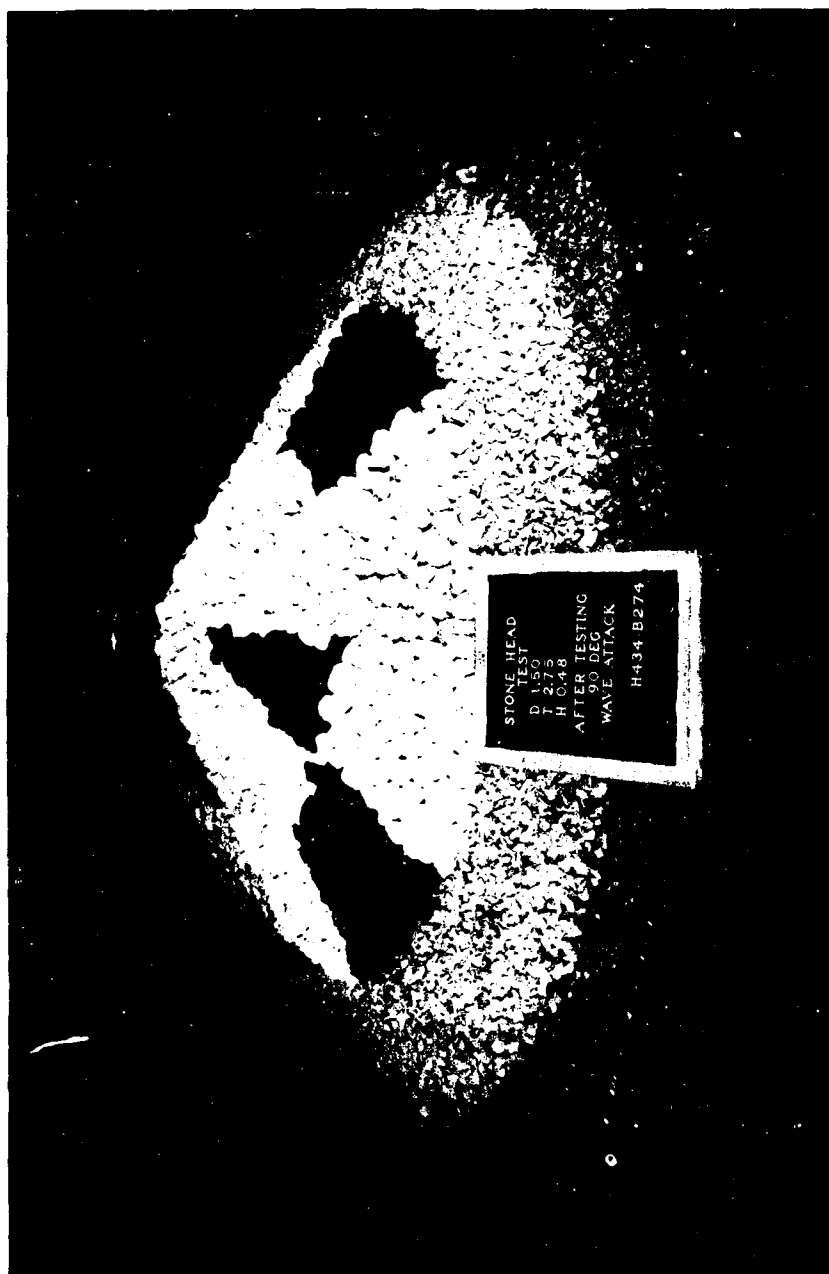


Photo 24. End view after attack of 2.75-sec, 0.48-ft waves; angle of wave attack = 90 deg; LV- on-2H-structure slope; stone armor



Photo 25. End view after attack of 1.25-sec, 0.56-ft waves; angle of wave attack = 135 deg; IV- on-2H-structure slope; stone armor



Photo 26. End view after attack of 1.50-sec, 0.52-ft waves; angle of wave attack = 135 deg; IV- on-2H-structure slope; stone armor



Photo 27. End view after attack of 2.00-sec, 0.51-ft waves; angle of wave attack = 135 deg; IV- on-2H-structure slope; stone armor



Photo 28. End view after attack of 2.75-sec, 0.48-ft waves; angle of wave attack = 135 deg; LV- on-2H-structure slope; stone armor

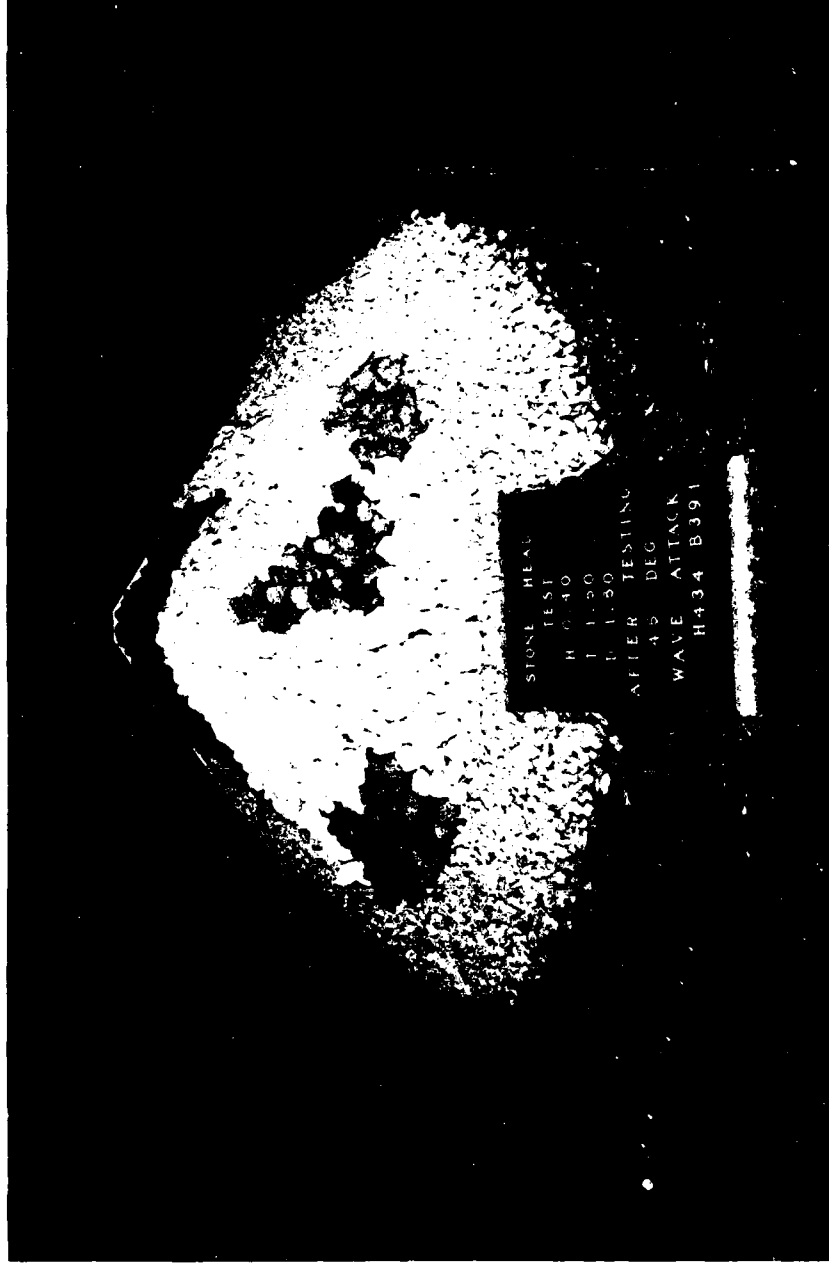


Photo 29. End view after attack of 1.50-sec, 0.40-ft waves; angle of wave attack = 45 deg; 1V- on-1.5H-structure slope; stone armor

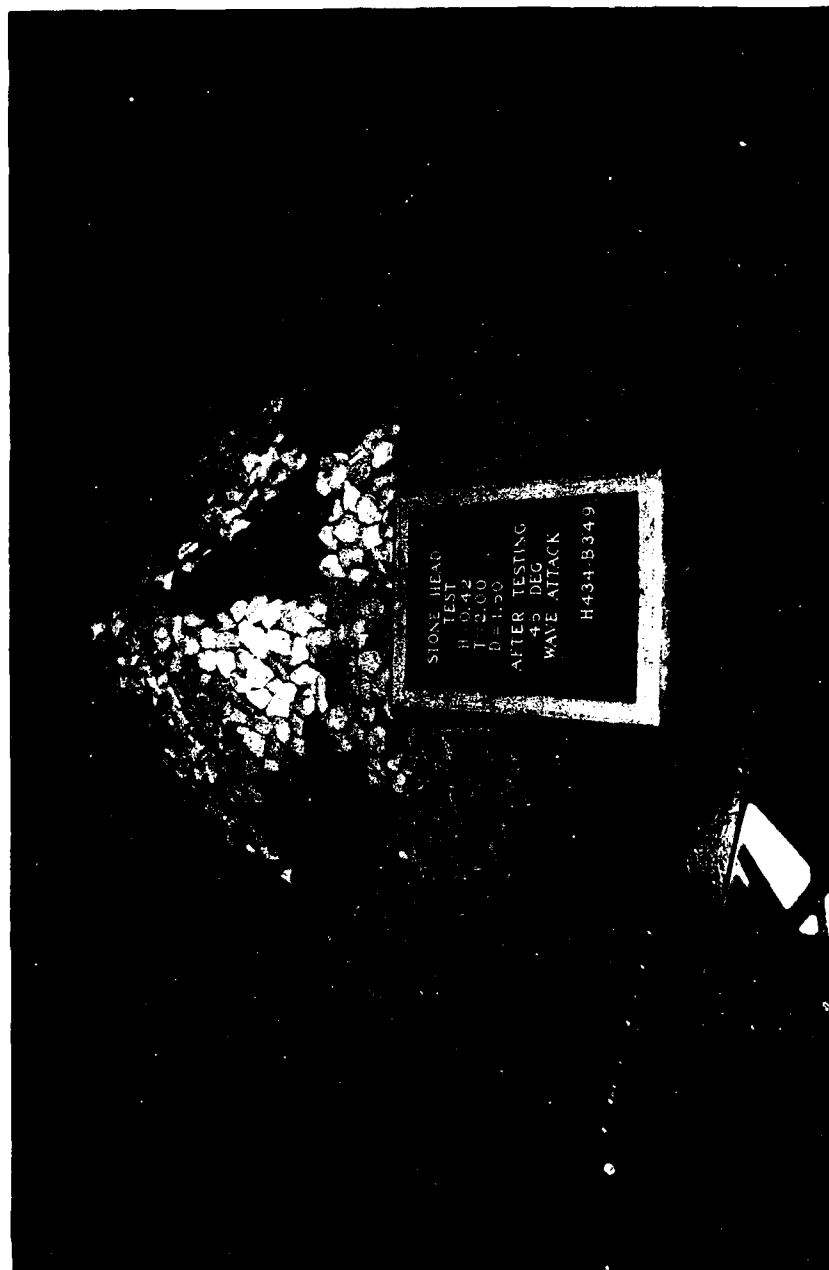


Photo 30. End view after attack of 2.00-sec, 0.42-ft waves; angle of wave attack = 45 deg; LV- on-1.5H-structure slope; stone armor



Photo 31. End view after attack of 2.75-sec, 0.53-ft waves; angle of wave attack = 45 deg; 1V- on-1.5H-structure slope; stone armor

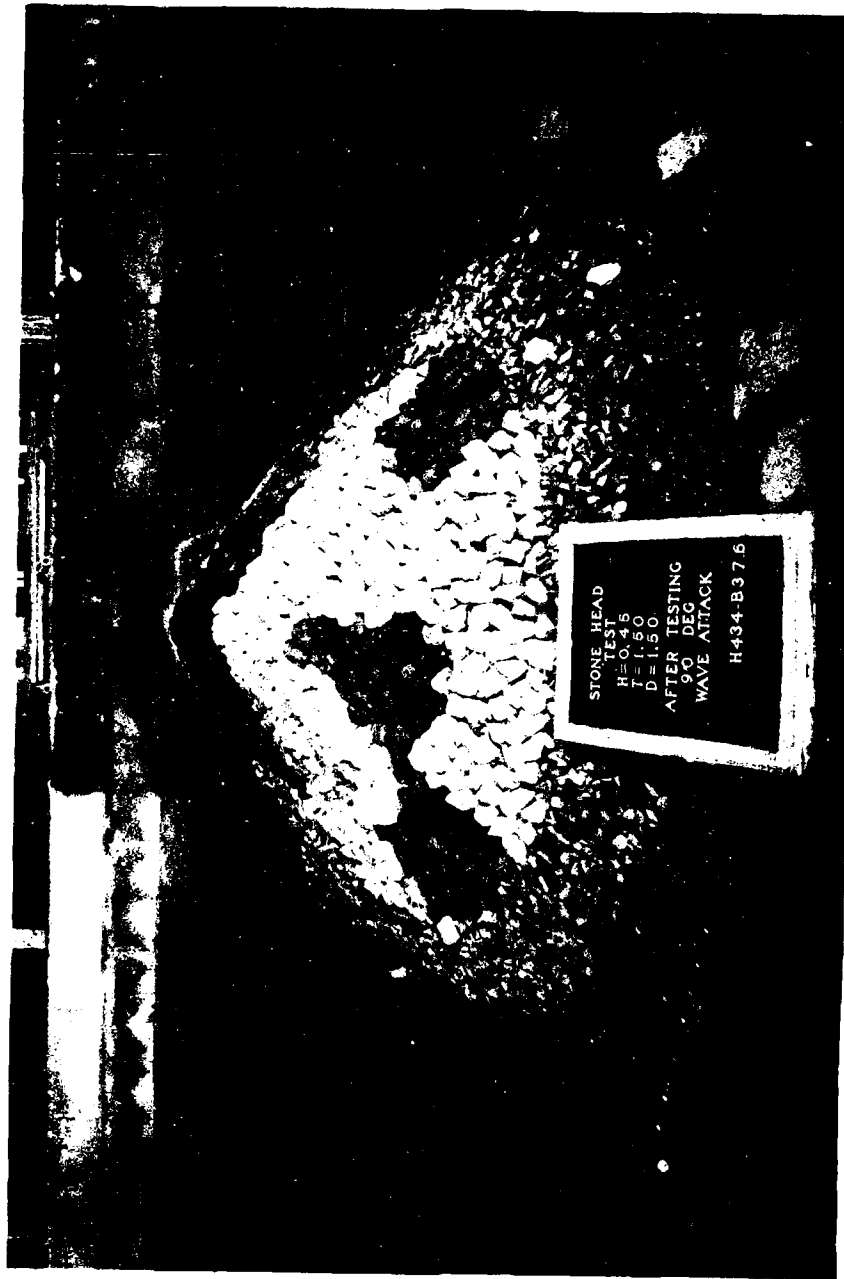


Photo 32. End view after attack of 1.50-sec, 0.45-ft waves; angle of wave attack = 90 deg; IV- on-1.5H-structure slope; stone armor

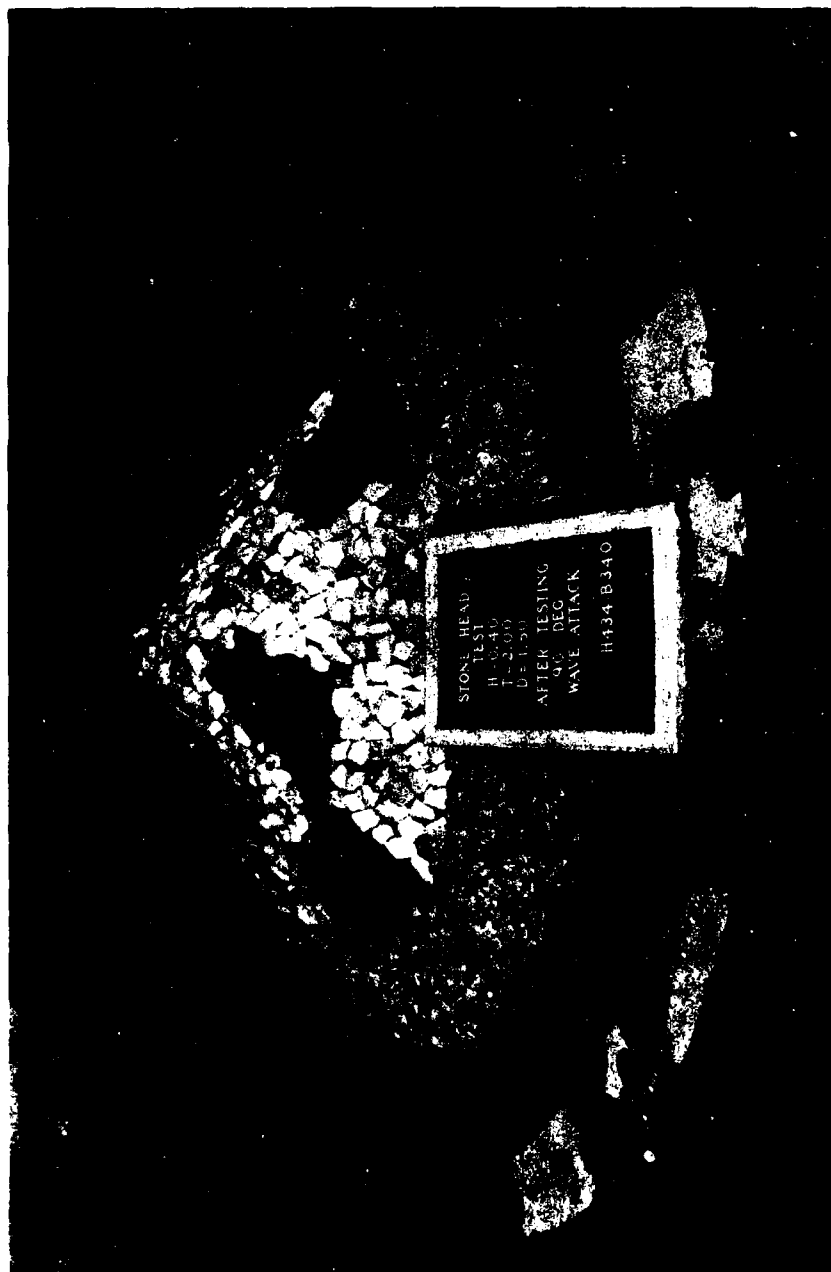


Photo 33. End view after attack of 2.00-sec, 0.40-ft waves; angle of wave attack = 90 deg; IV- on-1.5H-structure slope; stone armor

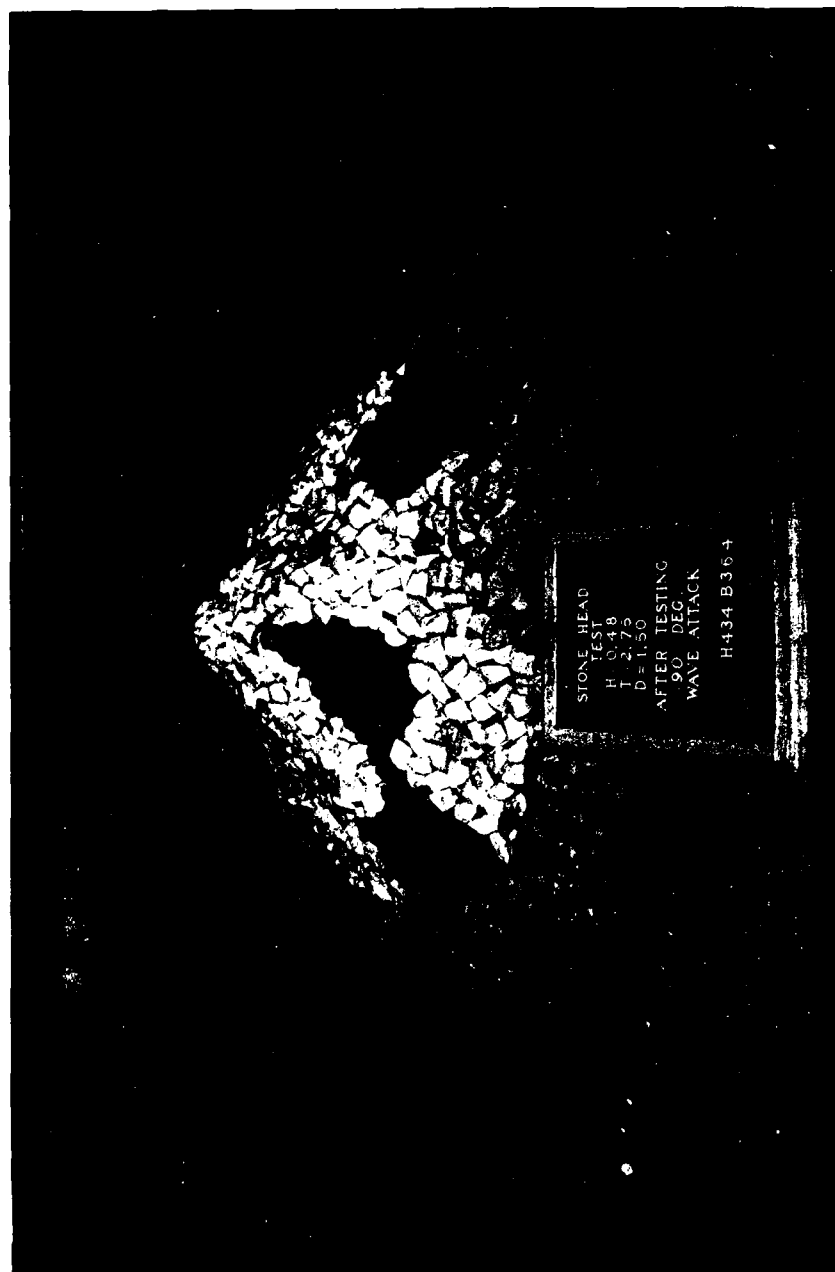


Photo 34. End view after attack of 2.75-sec, 0.48-ft waves; angle of wave attack = 90 deg; 1V- on-1.5H-structure slope; stone armor

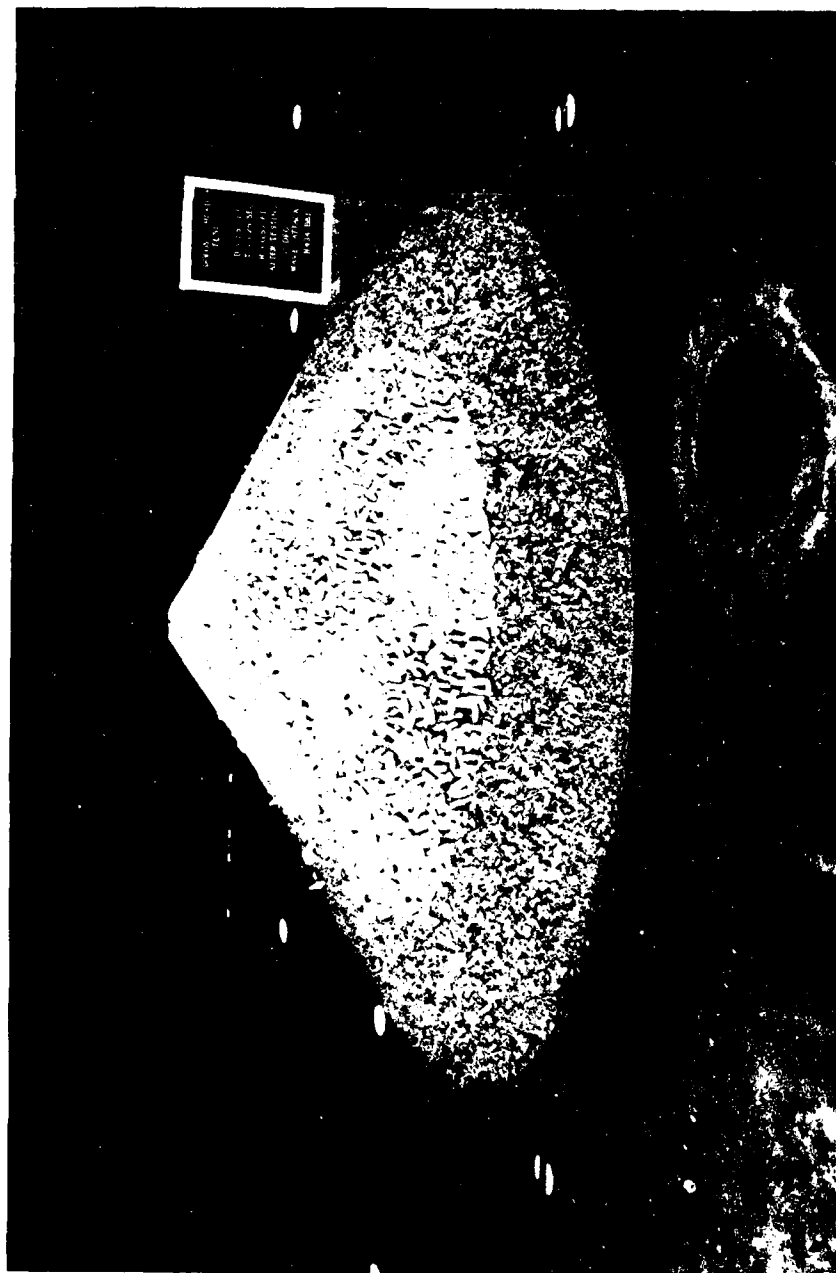


Photo 35. End view after attack of 1.25-sec, 0.57-ft waves; angle of wave attack = 0 deg; 1V- on-2H-structure slope; dolos armor

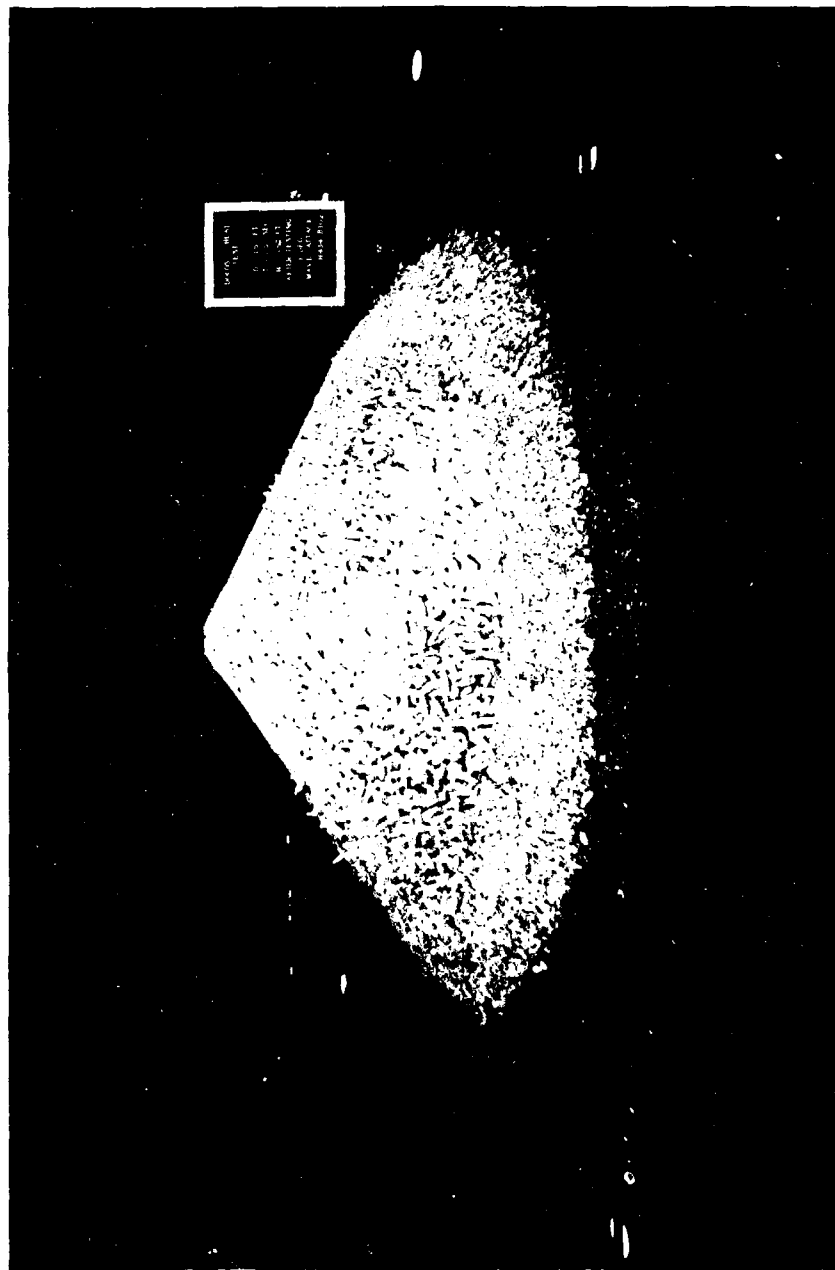


Photo 36. End view after attack of 1.50-sec, 0.52-ft waves; angle of wave attack = 0 deg; IV- on-2H-structure slope; dolos armor



Photo 37. End view after attack of 2.00-sec, 0.47-ft waves; angle of wave attack = 0 deg; LV- on-2H-structure slope; dolos armor



Photo 38. End view after attack of 2.75-sec, 0.54-ft waves; angle of wave attack = 0 deg; LV- on-2H-structure slope; dolos armor



Photo 39. Sea-side view after attack of 1.25-sec, 0.50-ft waves; angle of wave attack = 45 deg; LV- on-2H-structure slope; dolos armor

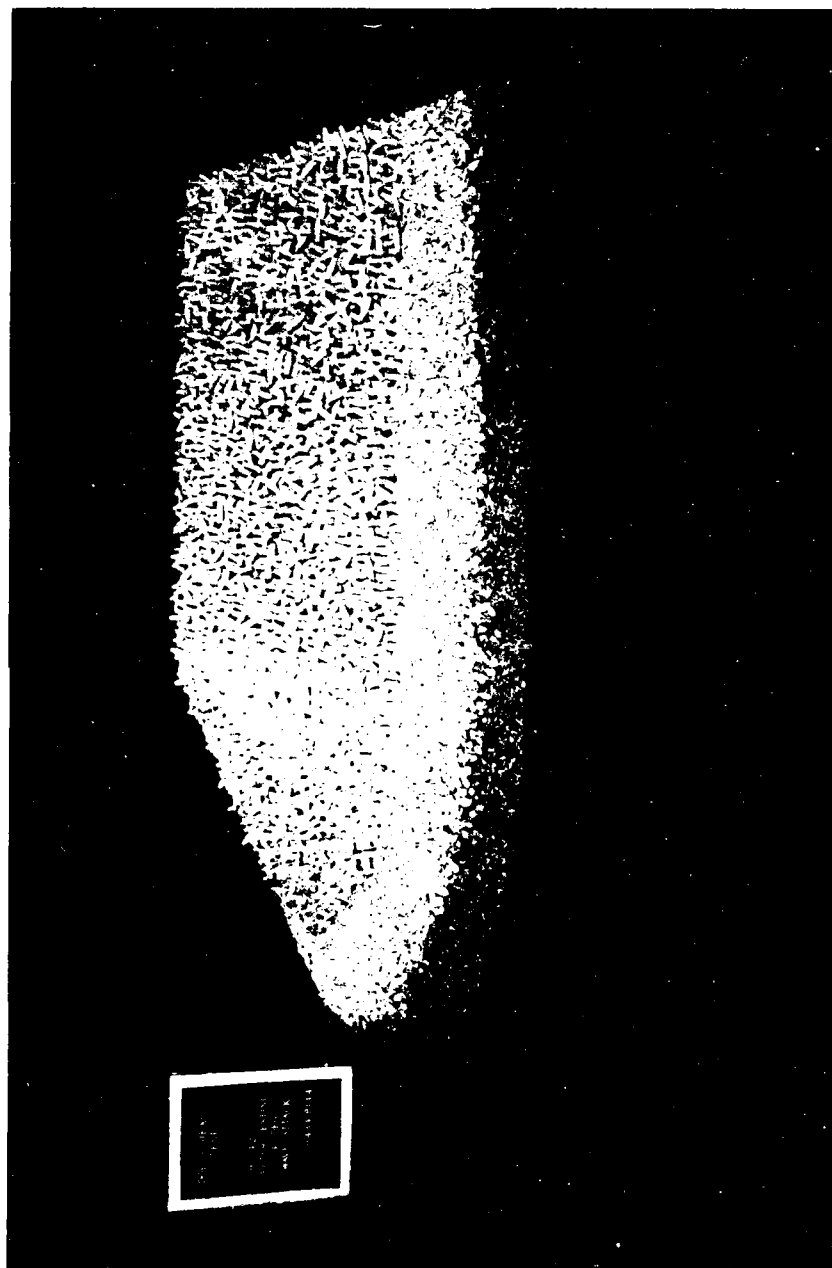


Photo 40. Sea-side view after attack of 1.50-sec, 0.42-ft waves; angle of wave attack = 45 deg; 1V- on-2H-structure slope; dolos armor



Photo 41. Sea-side view after attack of 2.00-sec, 0.45-ft waves; angle of wave attack = 45 deg; LV- on-2H-structure slope; dolos armor

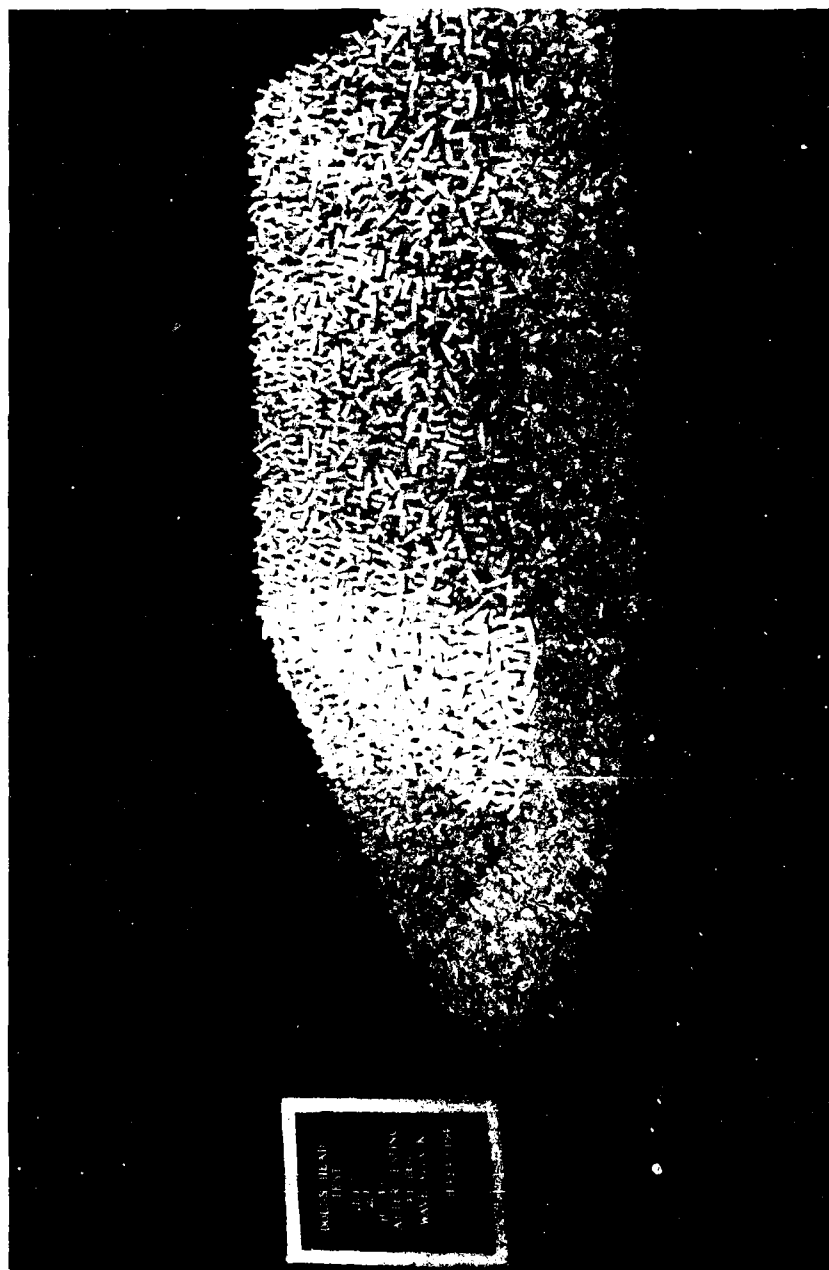


Photo 42. Sea-side view after attack of 2.75-sec, 0.45-ft waves; angle of wave attack = 45 deg; LV- on-2H-structure slope; dolos armor



Photo 43. End view after attack of 1.25-sec, 0.55-ft waves; angle of wave attack = 90 deg; IV- on-2H-structure slope; dolos armor

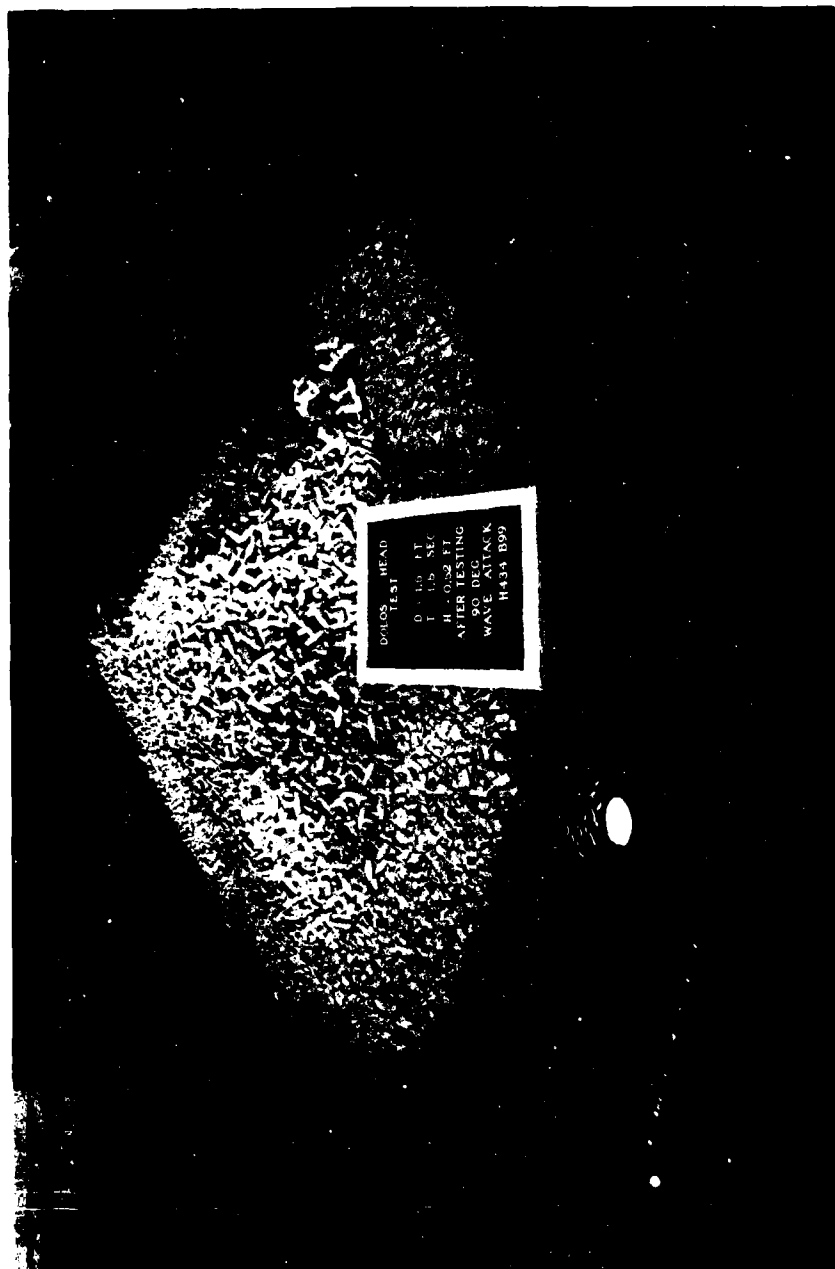


Photo 44. End view after attack of 1.50-sec, 0.52-ft waves; angle of wave attack = 90 deg; LV- on-2H-structure slope; dolos armor

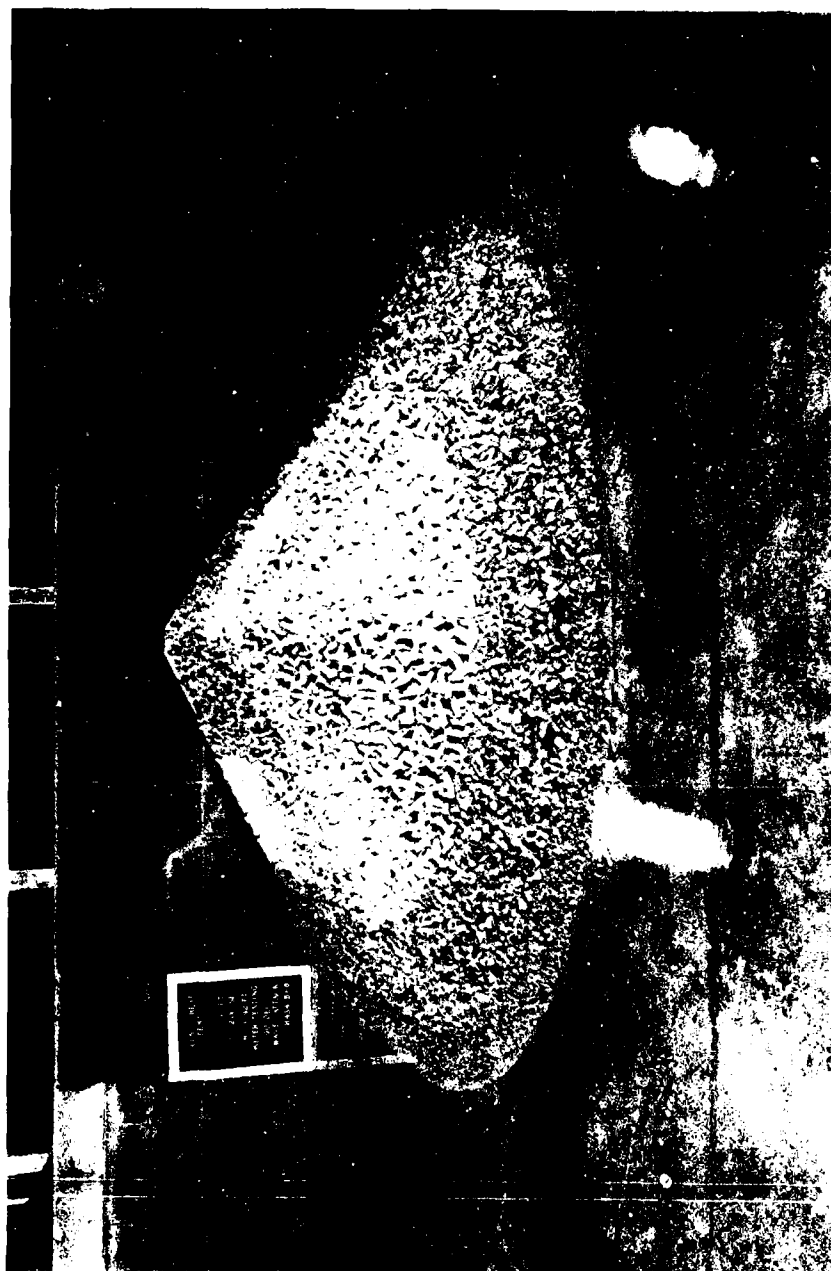


Photo 45. End view after attack of 2.00-sec, 0.42-ft waves; angle of wave attack = 90 deg; 1V- on-2H-structure slope; dolos armor

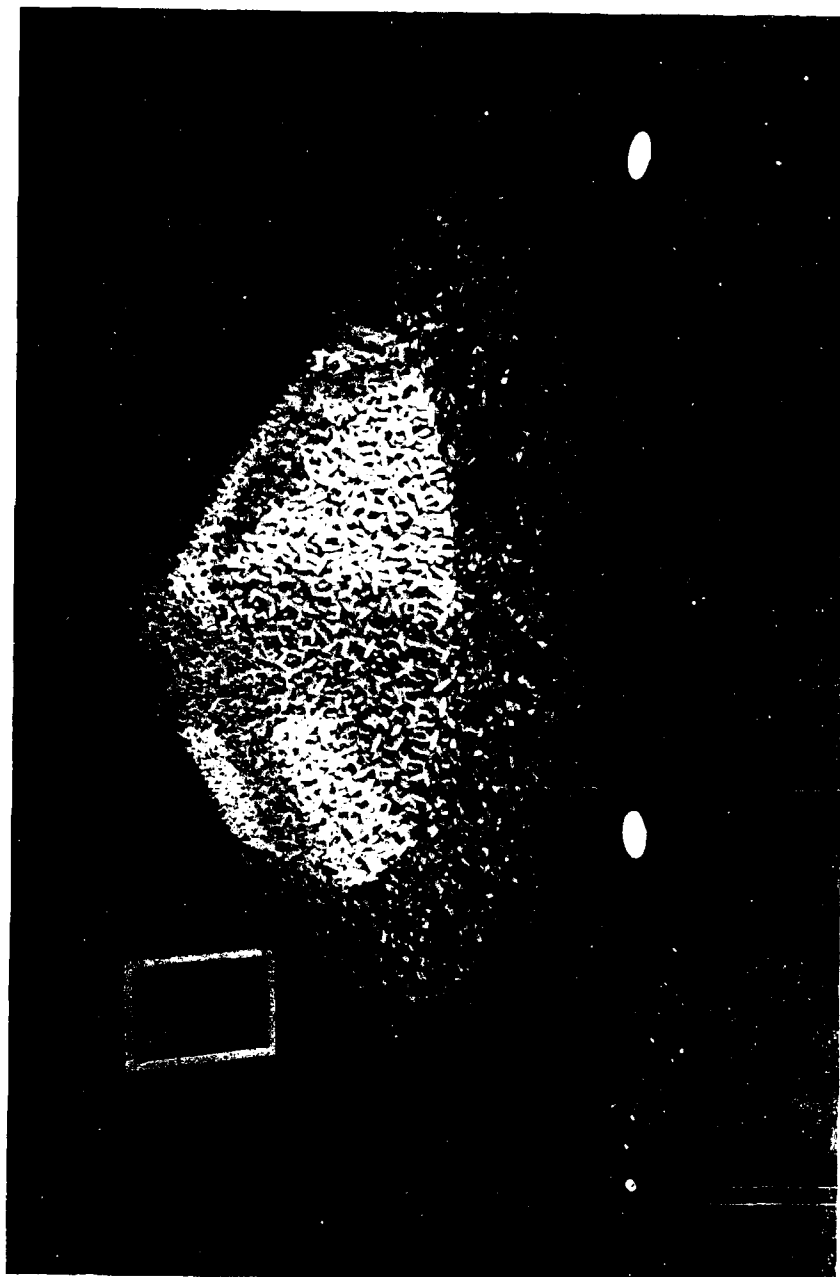
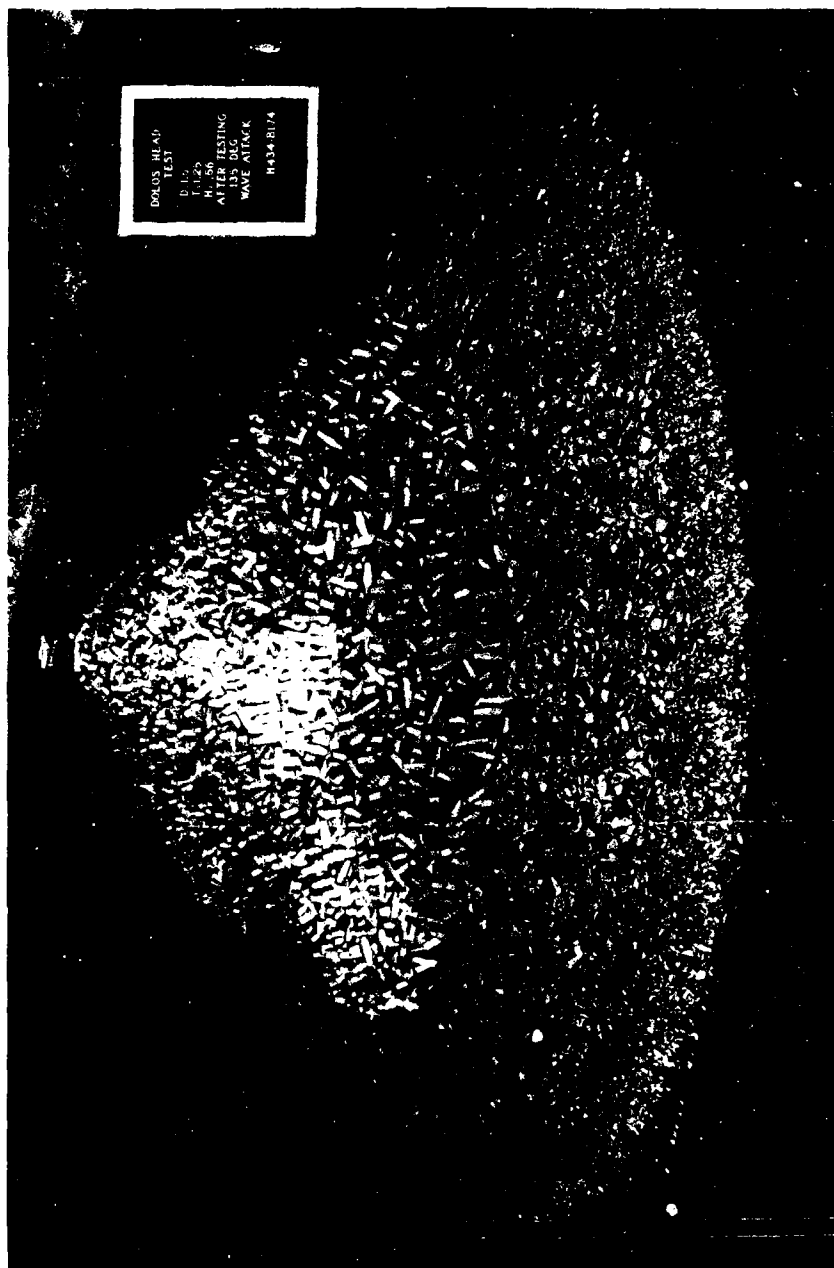


Photo 46. End view after attack of 2.75-sec, 0.50-ft waves; angle of wave attack = 90 deg; 1V- on-2H-structure slope; dolos armor



DOLOS H/A/O
TEST
D 1.2
T 1.25
H 1.56
TESTING
AT 135 DEG
135 DEG
WAVE ATTACK
H434-B1/4

Photo 47. End view after attack of 1.25-sec, 0.56-ft waves; angle of wave attack = 135 deg; 1V- on-2H-structure slope; dolos armor



Photo 49. End view after attack of 2.00-sec, 0.45-ft waves; angle of wave attack = 135 deg; LV- on-2H-structure slope; dolos armor

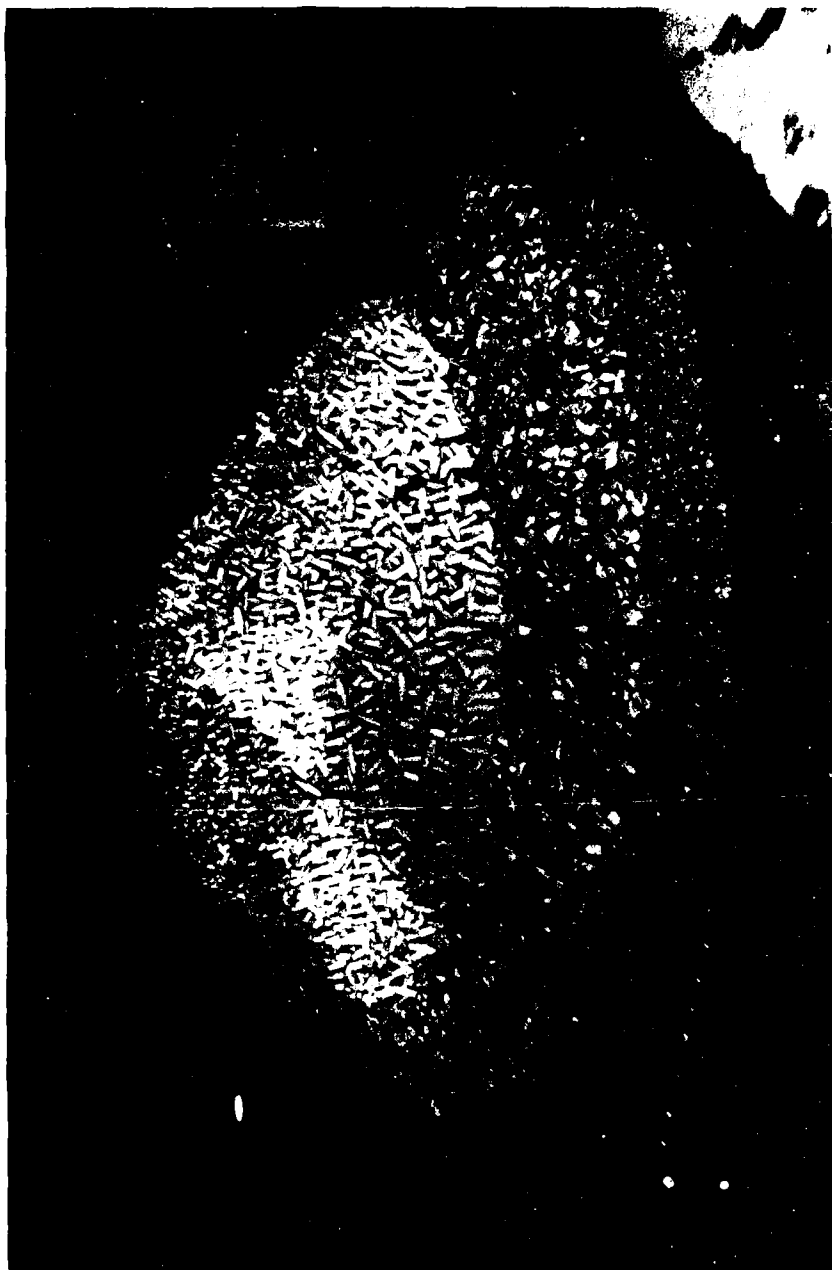


Photo 50. End view after attack of 2.75-sec, 0.42-ft waves; angle of wave attack = 135 deg; LV- on-2H-structure slope; dolos armor

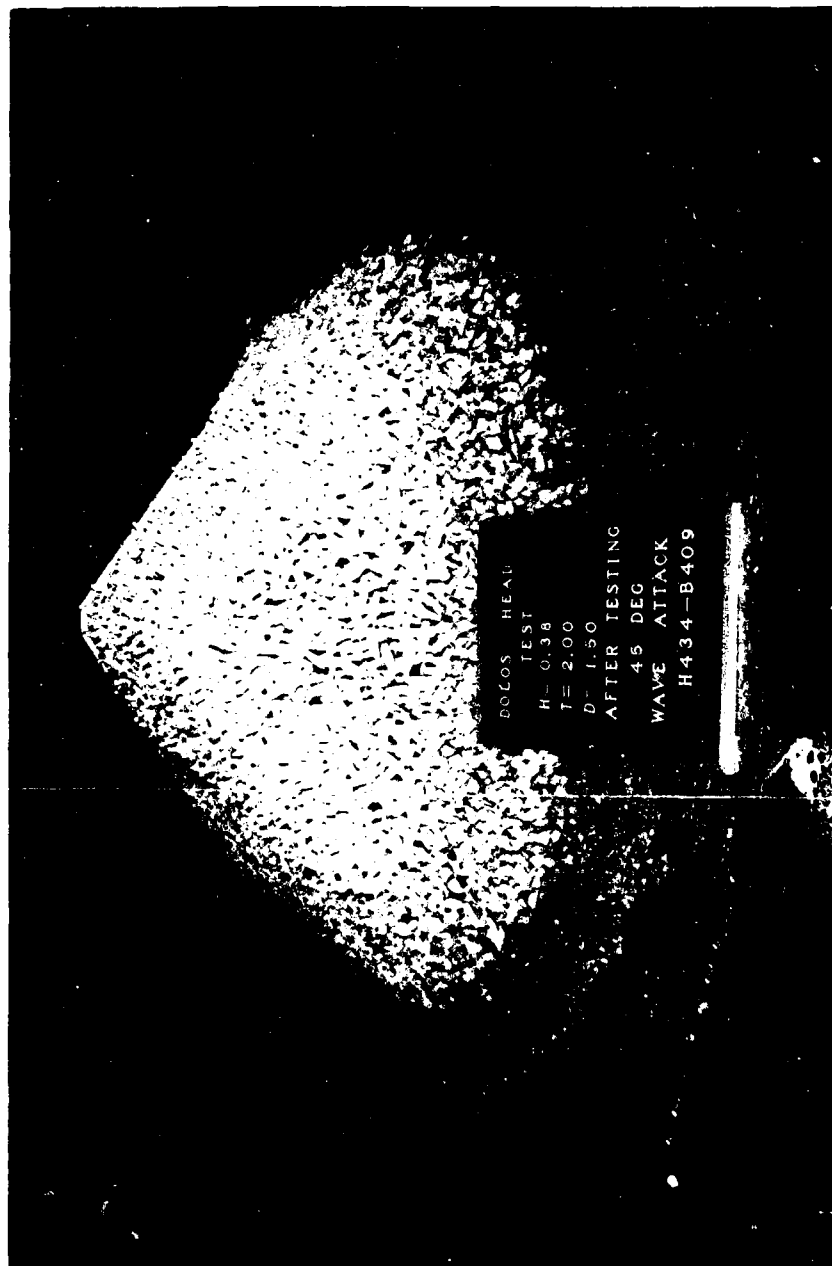
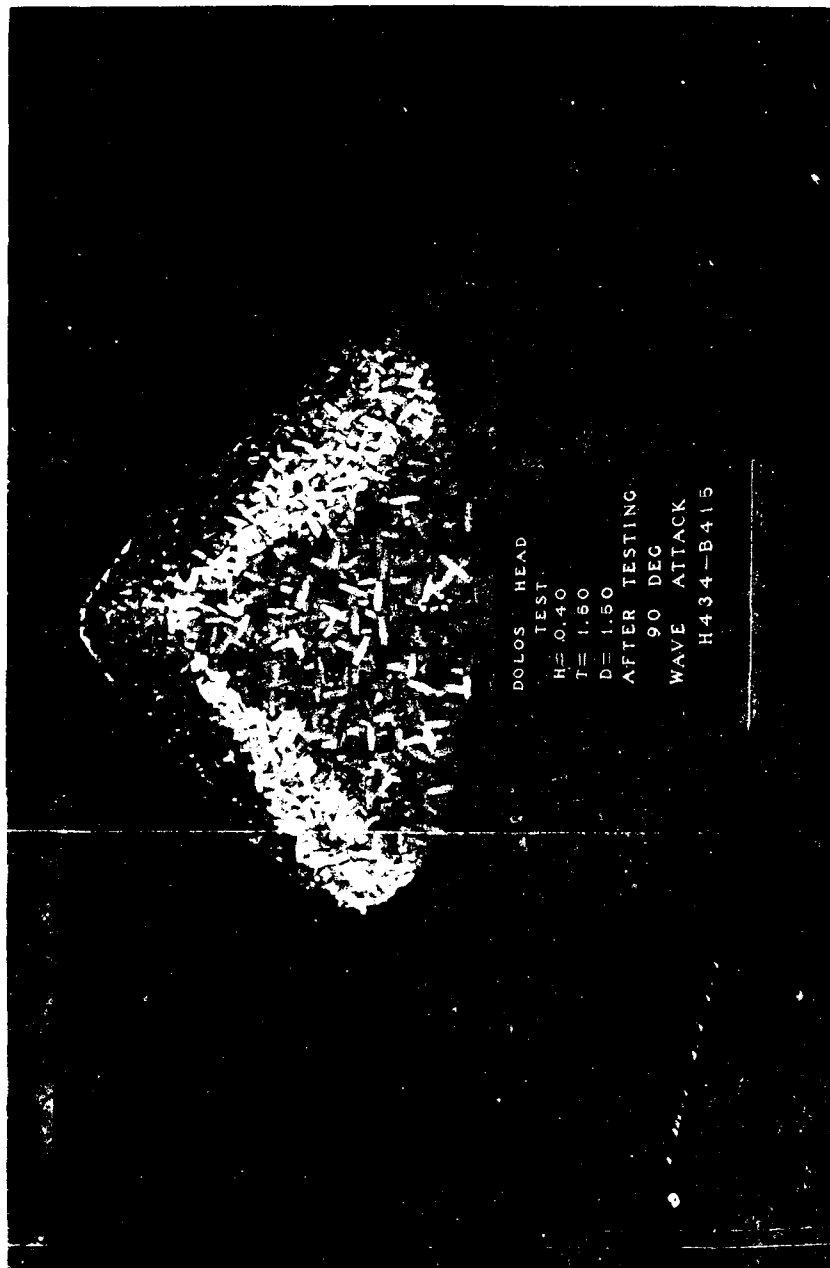


Photo 51. End view after attack of 2.00-sec, 0.38-ft waves; angle of wave attack = 45 deg; IV- on-1.5H-structure slope; dolos armor



DOLOS HEAD

TEST

H= 0.40

T= 1.50

D= 1.50

AFTER TESTING

90 DEG

WAVE ATTACK

H434-B415

Photo 52. End view after attack of 1.50-sec, 0.40-ft waves; angle of wave attack = 90 deg; LV- on-1.5H-structure slope; dolos armor

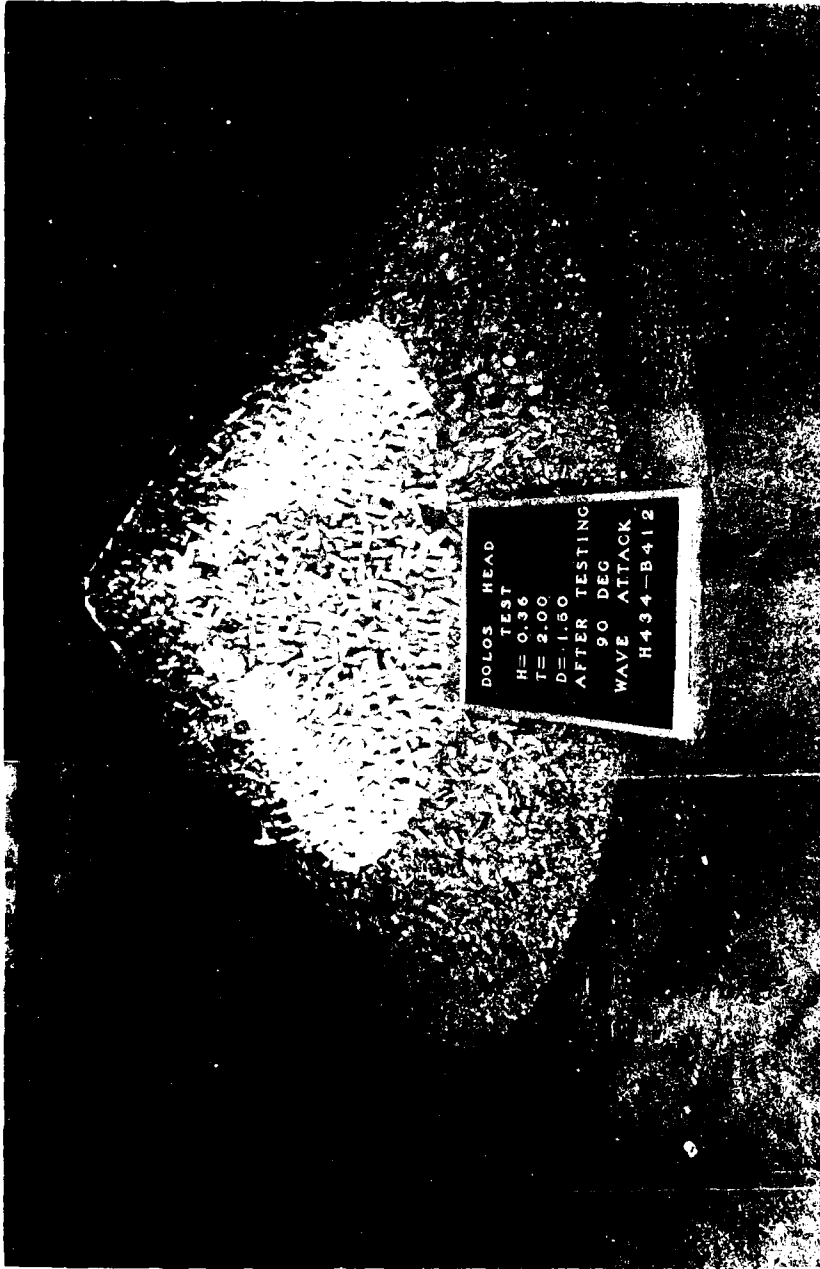


Photo 53. End view after attack of 2.00-sec, 0.36-ft waves; angle of wave attack = 90 deg; 1V- on-1.5H-structure slope; dolos armor

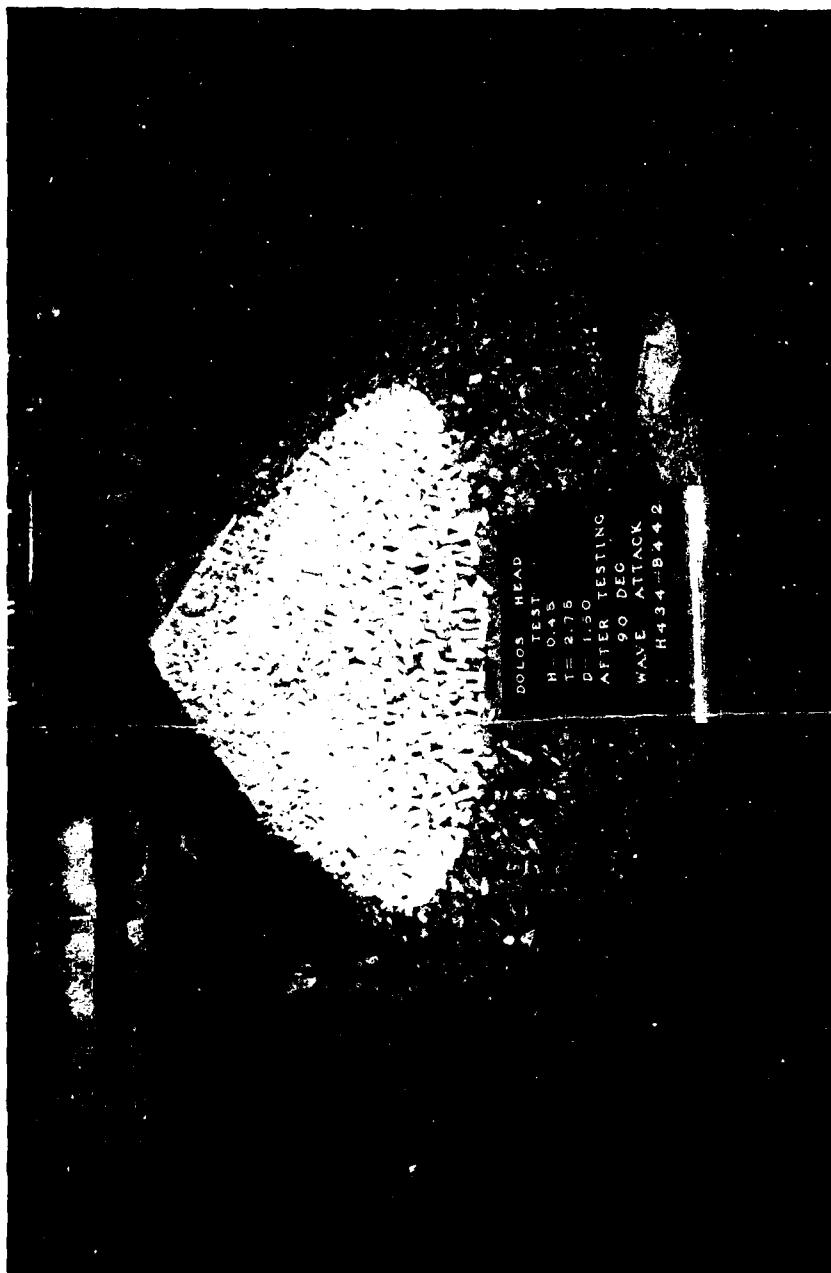


Photo 54. End view after attack of 2.75-sec, 0.45-ft waves; angle of wave attack = 90 deg; IV-- on-1.5H-structure slope; dolos armor

APPENDIX A: NOTATION

A	Surface area, ft^2
c	Coefficient
g	Acceleration due to gravity, ft/sec^2
H	Wave height, ft
H/L	Wave steepness
k_L	Shape coefficient
K_D	Stability coefficient
ℓ_a	Characteristic length of armor unit, ft
L	Length, wavelength, ft
n	Number of layers of armor units
N	Number of armor units
P	Porosity of breakwater material, percent
R_N	Reynolds stability number = $g^{1/2} H^{1/2} \ell_a / v$
T	Wave period, sec; time
V	Volume, ft^3
W	Weight, lb
α	Angle of breakwater slope, measured from horizontal, deg
cot α	Reciprocal of breakwater slope
β	Angle of wave attack, deg
γ	Specific weight, pcf
γ_a	Specific weight of armor unit, pcf
Δ	Shape of armor unit or underlayer material
ν	Kinematic viscosity of experimental fluid medium, ft^2/sec

Subscripts

a	Refers to armor unit
s	Refers to stability
w	Refers to water in which the structure is located

END

DATE
FILMED

3 88

DTIC